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The Petrology of the Las Canadas Volcanoes, Tenerife, Canary Islands

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Abstract. Tenerife is the largest of the seven Tertiary to Recent volcanic islands that make up the Canary Archipelago. The island is composed of volcanics belonging to the basanite-trachyte-phonolite assemblage that characterises many Atlantic islands. The most voluminous development of intermediate and salic volcanics has been in the centre of the island where the Las Canadas volcanoes arose upon a basement shield composed mainly of basanite and ankaramite flows, tuffs and agglomerates. The initial post-shield activity built the Vilaflor volcanic complex (Lower and Upper Canadas Series) that originally covered much of the underlying shield volcanics. A vast collapse of the complex, probably during post-Pleistocene times, in the centre of the island has left a large semi-circular wall, and provides an excellent vertical section through the complex. Quaternary volcanism within the collapsed area has built the twin, central-type volcanoes, Viejo and Teide, both of which have attendant satellite vents. That part of the Vilaflor Complex exposed in Las Canadas, together with the Viejo and Teide volcanoes, comprise the Las Canadas volcanoes.

Four distinct rock types can be recognised in these volcanoes, basanite, trachybasanite, plagioclase phonolite, and phonolite. Each rock type can be recognised chemically and mineralogically, but there is essentially a gradational series from basanite to phonolite that includes both aphyric and glomerophyric rocks. The volcanics are strongly undersaturated and sodic, and some of the phonolites are mildly peralkaline. Variations in degree of undersaturation, and trace element abundances indicate a number of cycles of activity which would be consistent with the known field relations.

Forsteritic olivine occurs in the basanites and trachybasanites but is not a stable phase in the more salic volcanics. Clinopyroxene is ubiquitous, varying in composition from titanaugite in the basanites to slightly sodic augite in the phonolites. Strongly sodic pyroxene is restricted to the groundmass of the microcrystalline phonolites along with aenigmatite and a kataphoritic amphibole. Plagioclase is found only in the groundmass of the basanites, but andesine and potash-oligoclase are common phenocryst minerals in the trachybasanites and plagioclase phonolites respectively, whereas the characteristic feldspar of the phonolites is anorthoclase.

The relatively smooth curves of major and trace element variation, the presence of accumulative volcanics at all stages of differentiation, zoning of the mineral phases, and the clustering of the phonolites around the low temperature trough in Petrogeny's Residua System, all indicate that the descent from basanite to phonolite has resulted from fractional crystallisation of a basanite parent magma. The trend of pyroxene crystallisation, and the fairly constant FeO/Fe_2O_3 ratio during fractionation indicate crystallisation under low PO_2 conditions.

Introduction

In recent years, with the development of the concept of ocean floor spreading and its importance in theories of continental drift, considerable attention has focussed on the oceanic islands. Most of these islands are composed of volcanic rocks derived from magmas whose primary origin lies within the mantle. Such magmas are produced, and ascend, free from the possibility of sialic contamination in the true oceanic environment, and are thus of considerable interest and importance to petrologists.

Surprisingly little is known in detail of the numerous Atlantic islands even though many of them are easily accessible and of considerable area. The Canary Islands group, for instance, covers some 7,000 km^2, with the largest island, Tenerife, over 2,000 km^2. The Canaries are situated off the north-west coast of Africa (Fig. 1), the eastern most islands, Lanzarote and Fuertaventura, lying well up on the continental rise of Africa. However, geophysical evidence (Dash and Bosshard, 1968; Macfarlane and Ridley, 1968, 1969) has shown that none of the western islands are underlain by sialic material, thus, although the depth to the Moho in this area is never less than 11 km, the islands can be justifiably called oceanic.

The Canary Islands volcanics are characteristically alkaline and undersaturated, and belong to the basanite (alkali olivine basalt) -trachyte-phonolite suite. Hausen (1956, 1958, 1959, 1962) and Fuster *et al.* (1968a, b, c, d) tabulate many analyses from Tenerife, Gran Canaria Fuertaventura, and Lanzarote, which in conjunction with the data of Fuster *et al.* (1954) give a broad impression of the major element geochemistry of the Canarian volcanoes.

Basanites and ankaramites predominate on the islands of Hierro, Gomera, La Palma, and Lanzarote, almost to the exclusion of all other rock types. On Tenerife and Gran Canaria the volcanics range from basanites to trachytes and phonolites and some oversaturated salic types are found on Gran Canaria. Intermediate members are also present on these latter two islands, variously termed trachybasalt, trachyandesite, andesite plagioclase-phonolite, mafic phonolite, and ordonchite. On Fuertaventura the rocks range from undersaturated ultrabasics, through spilites and trachytes, to extrusives with rhyolitic affinities (Hausen, 1958).

Coarse grained intrusives outcrop in the deeply eroded parts of Gomera, La Palma and Fuertaventura, whereas coarse grained zenoliths occur in volcanics on Tenerife (Borley, Suddaby, and Scott, 1969), Gran Canaria (Frisch and Schmincke, 1968) and Lanzarote. The garnet and phlogopite bearing xenoliths reported from Lanzarote (Fuster *et al.*, 1968) appear to be of a more primitive origin than those from other islands.

No detailed geochemistry is available for any of these islands, even though they possess a wide and interesting variety of rock types. The study presented here was part of an examination of the geology of Las Canadas, a mountainous, volcanic region in the central part of Tenerife (Fig. 1). This island is particularly interesting because of the large volume of intermediate and salic volcanics exposed (Ridley, 1969), especially in the Las Canadas area. These volcanics rest on the basement shield volcanics (Series I and II) of basanites and ankaramite flows intercalated with basic tuffs and agglomerates. These basic shield volcanics are the oldest subaerial formation on Tenerife, dated by Abdel-Monem *et al.* (1968) at 16—7.2 m.y.

The areally extensive intermediate and salic volcanics that were derived from the Las Canadas area have been devided by Fuster *et al.* (1968) into a lower unit (Lower Canadas Series) and an upper unit (Upper Canadas Series). In the terminology of the present study, these units together form the Vilaflor Complex. In addition, the major Quaternary volcanism on Tenerife has been centred on the Las Canadas area resulting in two large central type volcanoes, Viejo (3,303 m)

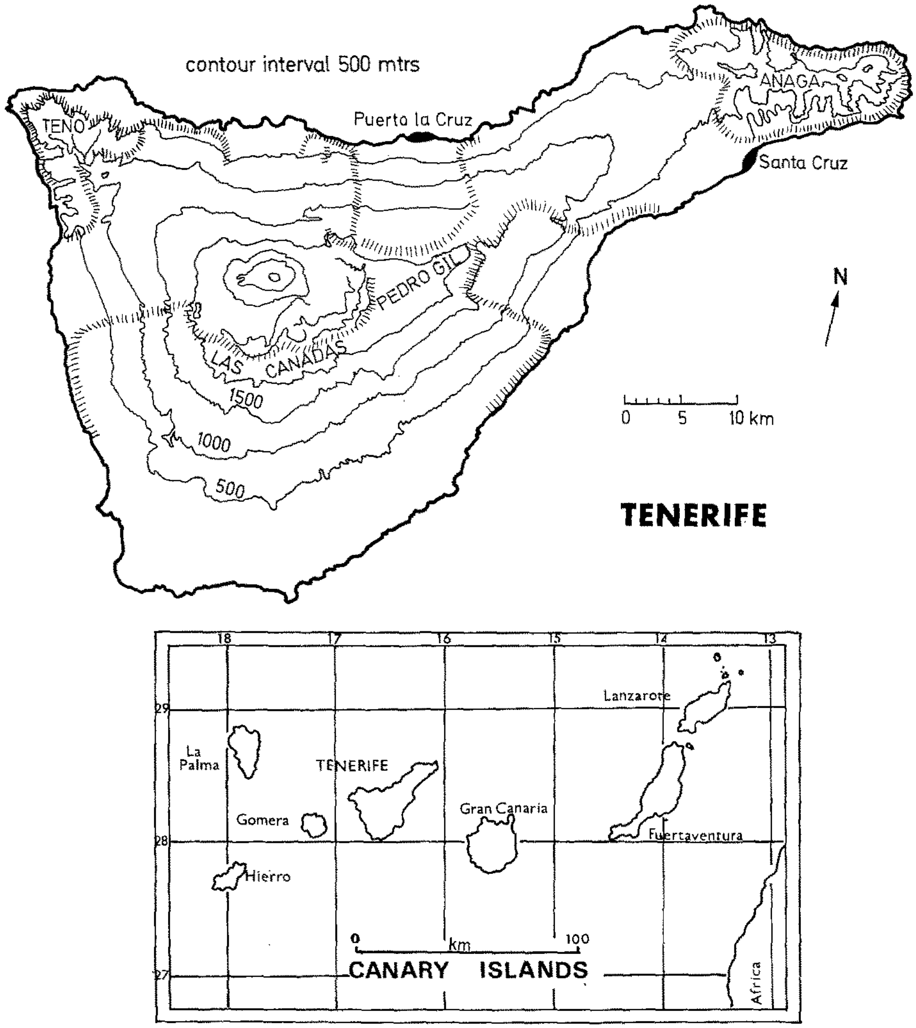

Fig. 1. Physiography of Tenerife and the position of the Canary Islands

and Teide (3,717 m)). Exposure is limited to the latest intermediate and salic flows and pyroclastics that were produced by these two volcanoes.

The present study examines the petrology of a representative suite of volcanics from the Vilaflor Complex and the Viejo-Teide volcanoes. Emphasis is laid on the major and minor element abundances, but selected mineralogical aspects are also discussed.

Classification and Petrography

The classification is based broadly on that already in use for some oceanic islands (Baker *et al.*, 1964; Le Maitre, 1962; Tilley and Muir, 1964) and utilises the Thornton-Tuttle Index (normative Qz + Or + Ab + Ne + Le + Ks) as shown in Fig. 2.

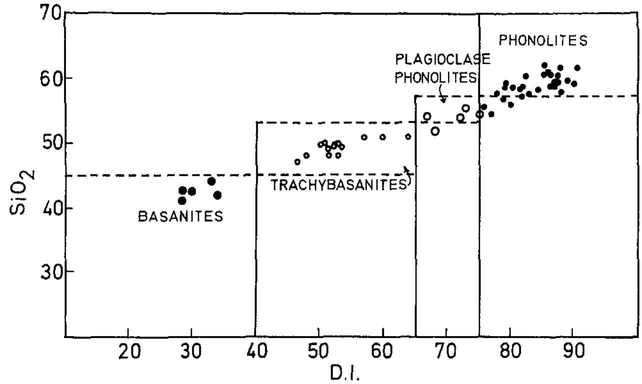

Fig. 2. Classification of Las Canadas volcanics. D. I.-Thornton-Tuttle Index

The divisions are based upon chemical criteria but do correspond to well defined petrographic differences in the rocks. The attendant nomenclature indicates the generally undersaturated and alkaline nature of the rocks. The classification is thus based on the following criteria:

Rock name	Differentiation index	Silica content	Alkali's
Basanite	<40	<45	<7
Trachybasanite	40—65	45—53	7—9
Plagioclase phonolite	65—75	53—57	9—12.5
Phonolite	>75	>57	>12.5

The term basanite has already been used extensively on Tenerife (Smulikowski *et al.*, 1946; Hausen, 1956), and is particularly useful in indicating the markedly undersaturated nature of the basic rocks. It was preferred to alkali olivine basalt which has now been used to describe a great variety of rocks of significantly different chemistry in oceanic islands (Le Maitre, 1962; Baker *et al.*, 1964; Macdonald and Katsura, 1964; Baker, 1969).

The trachybasanites and plagioclase phonolites are comparable, in terms of differentiation index, to the trachybasalts or Hawaiites, and the trachyandesites or mugearites, respectively of other oceanic islands. Both these terms have already been used on Tenerife, and plainly indicate the undersaturated, alkaline nature of the intermediate volcanics. The term phonolite is used only in a general way as strictly, from a chemical view point, some of the volcanics should be termed phonolitic trachytes, containing less than 5% normative nepheline. Even these types however can contain significant modal nepheline.

Basanites. These are divided into porphyritic and aphyric types, the latter particularly abundant as dikes (Fig. 3a). They contain abundant phenocrysts of olivine, zoned pyroxene, and homogeneous titanomagnetite. The pyroxene may be varying shades of purplish brown, or zoned from a pale green diopsidic core (2 V 53°) to a purplish rim (2 V 41—46°, $z \wedge c$ 46°) of titanaugite. Olivine (12 to 15% Fa) is commonly less abundant than pyroxene and forms colourless anhedra

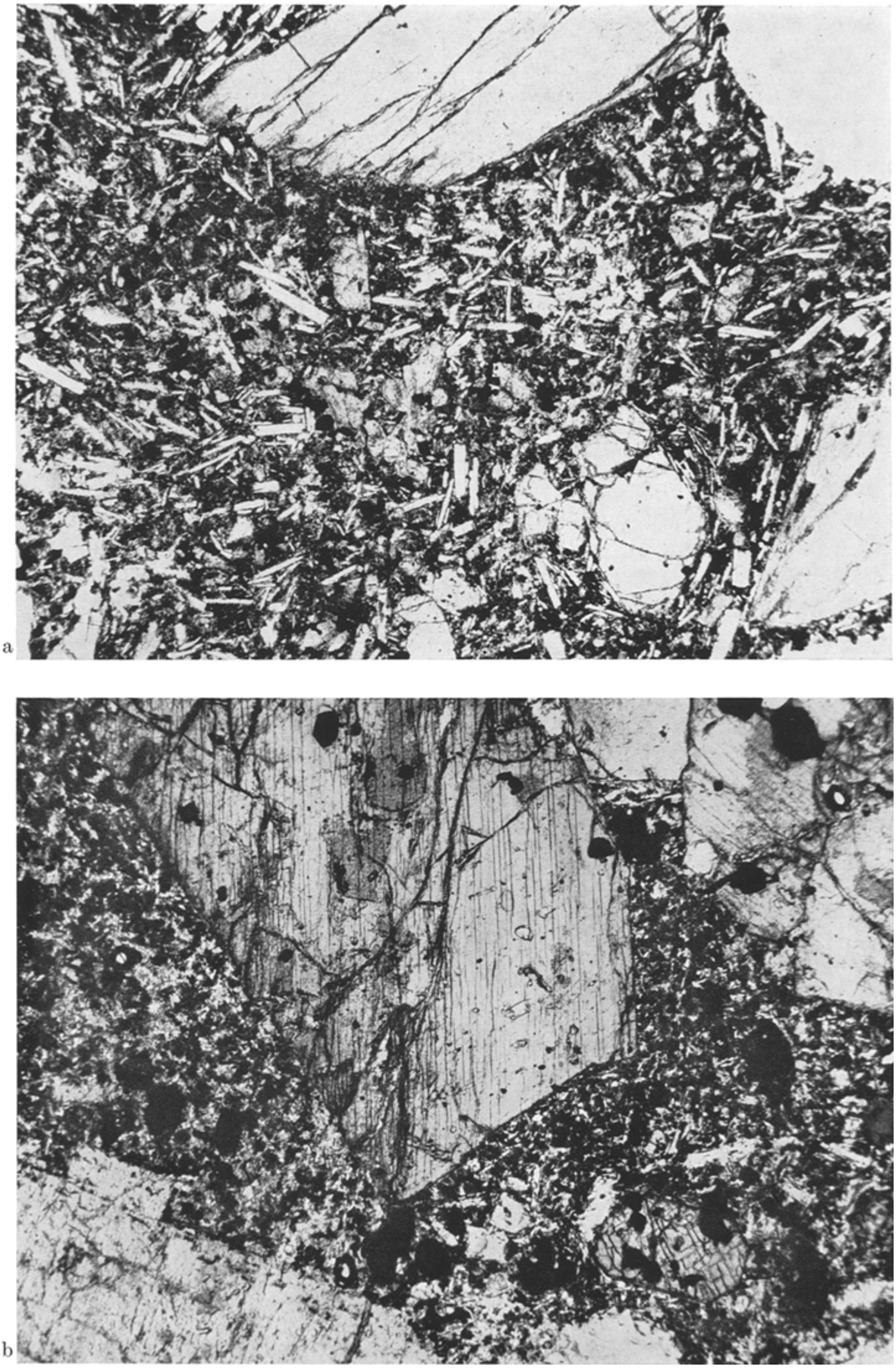

Fig. 3. a. Euhedra of olivine and diopsidic augite in a groundmass of olivine, titanaugite titanomagnetite, and labradorite. Basanite. Lower Canadas Series. b. Large euhedra of titanaugite showing patchy extinction. Plagioclase phenocryst, bottom left, with microphenocrysts of titanomagnetite. Pyroxene trachybasanite. Lower Canadas Series

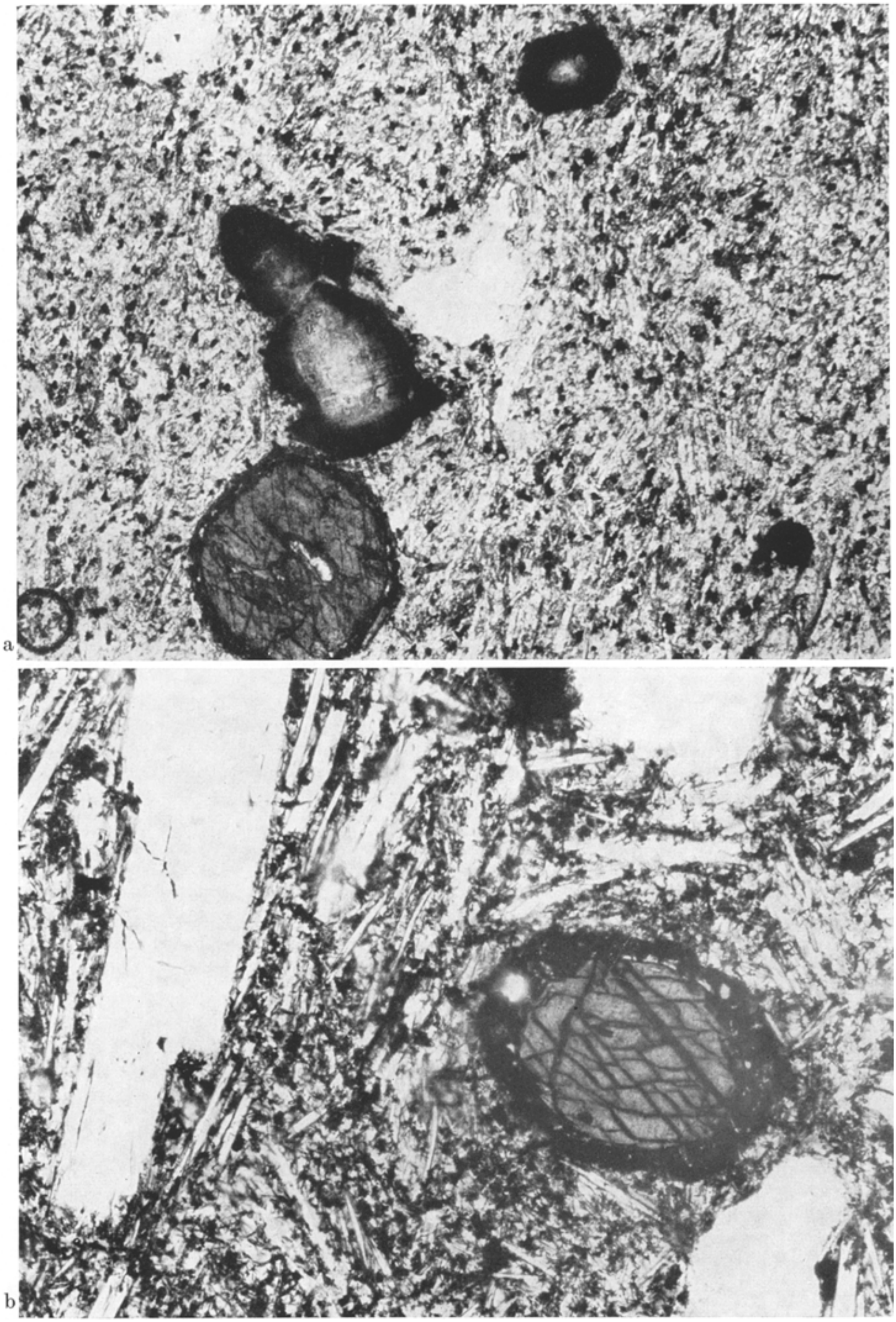

Fig. 4. a. Phenocrysts of deep brown amphibole rimmed with granular magnetite. Turbid, anhedral nosean with characteristic dark rim. Sub-trachytic groundmass of alkali feldspar, magnetite, and green pyroxene. Plagioclase phonolite. Las Pilas volcano. Lower Canadas Series ? b. Anhedral brown amphibole rimmed by magnetite, and laths of oligoclase rimmed by calcic anorthoclase. Groundmass of potash oligoclase, and magnetite. Plagioclase phonolite. Lower Canadas Series

rarely rimmed by iddingsite. Titanomagnetite anhedra are commonly enclosed in pyroxene and olivine, but appear to have crystallised throughout the cooling history of the basanites. Titanaugite, olivine and opaque are joined by labradorite (An 60) in the equigranular groundmass. Some of the very recent flows also contain significant intergranular glass.

The aphyric types are identical texturally to the groundmass of the porphyritic types, but have not been observed as flows.

Trachybasanites. The porphyritic types are commonly glomerophyric (Fig. 3b) with abundant laths of sodic labradorite, up to 8 mm long, and titanaugites up to 4 mm. The pyroxene is a purplish titanaugite (Table 1) associated with anhedral, colourless olivine (15—25% Fa), and titano-magnetite. The opaque commonly contains exsolved ilmenite lamellae and some unanalysed samples contained both hematite and pseudobrookite associated with very reddened olivines. The groundmass of the Viejo trachybasanites contains a high proportion of dark brown glass packed with feldspar microlites and crystallites of pyroxene and opaques.

Aphyric trachybasanites occur, but are not common, and are very often strongly oxidised or weathered. They appear to be similar to the groundmass of the porphyritic types.

Plagioclase Phonolites. Porphyritic types (Fig. 4a) contain phenocrysts of andesine (An 50—30) surrounded by a rim of potash oligoclase (Muir and Tilley, 1961). Clinopyroxene may be a major phenocryst, occurring in pale green euhedral clusters (2 V 56—58°, $z \wedge c$ 29—25°), but is very variable. A deep brown, strongly pleochroic amphibole (X-stray yellow, Y-reddish brown, Z-foxy brown$_3$ $z \wedge c$ 12—14°) is ubiquitous, forming laths up to 4 mm long. It displays every stage of oxidation from iron ore development along cleavages and rims, to clusters of opaques and pale brown pyroxene that have completely replaced the original amphibole. In only very rare cases does the amphibole appear to be stable in its final environment. Phenocrysts of nepheline, hauyne or nosean are characteristic of a group of plagioclase phonolites from Las Pilas. The groundmass of these flows is composed almost entirely of feldspar. The general lack of well defined laths, absence of polysynthetic twinning and low R. I. suggest that it may be sodic anorthoclase. Small shreds of pyroxene and brown amphibole may be associated with the feldspar.

Phonolites. Well crystalised varieties (Fig. 5a) are almost restricted to the Vilaflor Complex, and many of these are porphyritic. The differing degrees of crystallisation between the Vilaflor phonolites and the Viejo-Teide phonolites is probably partly due to the lack of good exposures of the central parts of the Viejo-Teide flows. The microcrystalline phonolites contain tabular phenocrysts of anorthoclase (Fig. 5a) displaying either quadrille or fine lamellar twinning. The phenocrystal pyroxene is a pale green, weakly pleochroic sodic augite (Table 1), and occasionally this is rimmed by a deep green variety ($z \wedge c$ 10—15°) similar to the groundmass pyroxene. Preliminary X-ray data suggests that this deep green variety is strongly acmitic. Microphenocrysts of dark brown amphibole and reddish brown pleochroic mica are also common. Nepheline forms cubic microphenocrysts (Fig. 5a) and is invariably rimmed by aegerine augite or aenigmatite. Rare flows contain large nosean anhedra with a colourless core and either a dark grey or pale blue rim.

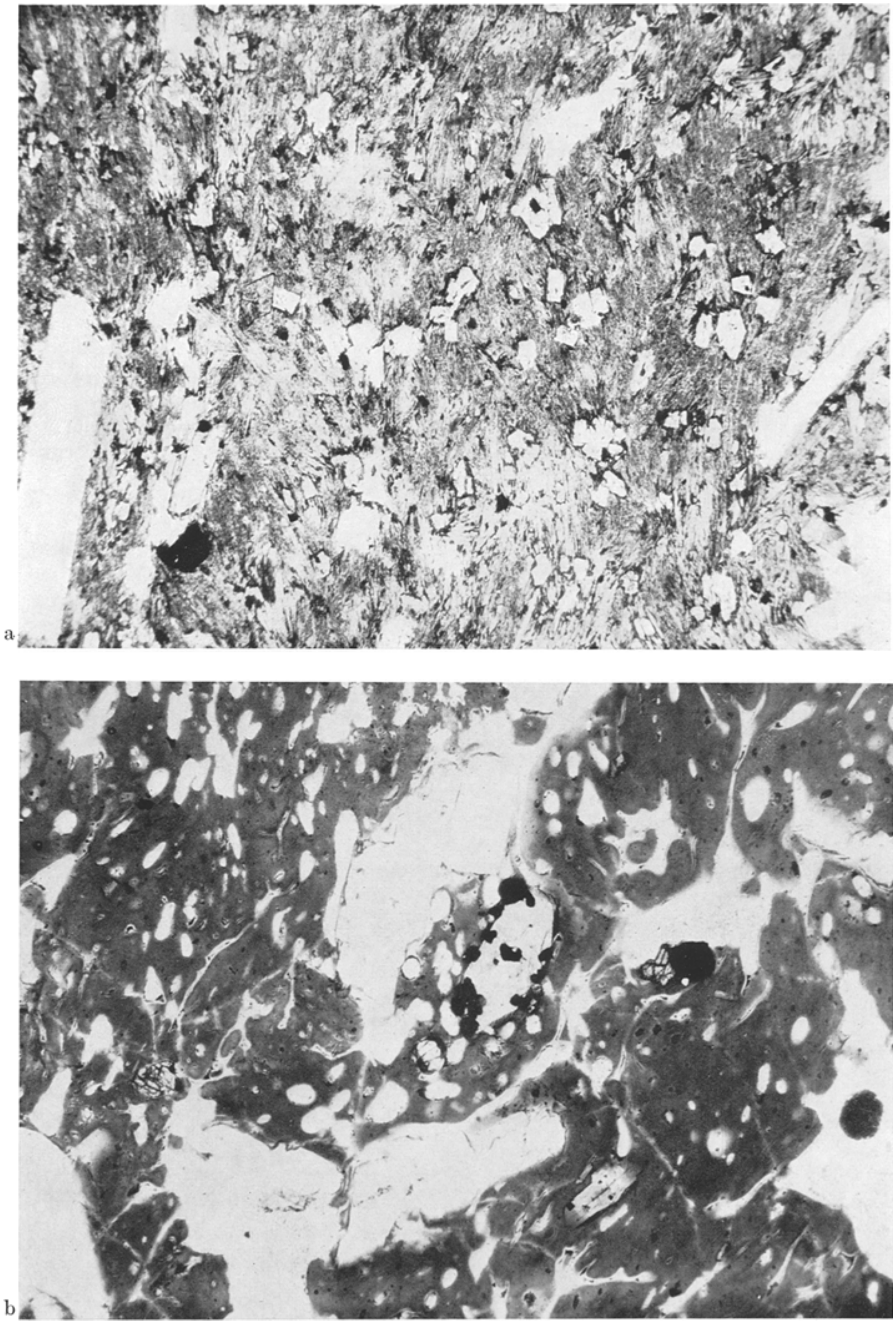

Fig. 5. a. Laths of anorthoclase with microphenocrysts of sodic augite anorthoclase and euhedral nepheline, the latter commonly rimmed by aegirine augite, aenigmatite, and magnetite. Groundmass has a felted texture, and is composed of anorthoclase, aegirine augite aenigmatite and magnetite. Phonolite sill. Upper Canadas Series. b. Phenocrysts of subhedral anorthoclase and pale green sodic augite associated with small magnetite grains. Groundmass of deep brown vesicular glass. Hyalophonolite. Teide

Table 1. *Chemical composition, structural formulae, and optical properties of some Las Canadas pyroxenes*

	P 191	P 7	P 6	P 40	P 183	26
SiO_2	48.40	46.46	49.48	53.24	53.17	53.2
Al_2O_3	6.52	4.91	4.45	2.77	1.85	1.35
TiO_2	2.72	5.54	2.62	1.43	0.91	0.88
FeO	3.91	6.91	5.88	4.66	5.92	
Fe_2O_3	3.85	3.02	1.94	2.31	2.66	9.6
MnO	0.15	0.25	0.26	0.44	0.66	0.84
MgO	12.95	12.64	13.09	13.76	12.95	12.3
CaO	21.24	20.14	21.51	20.55	21.17	20.6
Na_2O	0.59	0.83	0.92	1.07	1.24	1.2
Total	100.33	100.70	101.17	100.23	100.53	100.0
Structural formulae on the basis of 6 oxygens per unit cell XYZ_2O_6.						
Si_{IV}	1.800	1.736	1.836	1.954	1.957	1.968
Al_{IV}	0.200	0.215	0.164	0.046	0.043	0.010
Ti_{VI}	—	0.049	—	—	—	—
Al_{VI}	0.085	—	0.030	0.073	0.036	0.049
Ti_{III}	0.076	0.106	0.072	0.039	0.024	0.025
Fe	0.107	0.084	0.054	0.063	0.072	
Mg_{II}	0.722	0.708	0.728	0.758	0.712	0.686
Fe	0.121	0.215	0.182	0.142	0.180	0.300
Mn	0.005	0.008	0.008	0.016	0.020	0.026
Ca	0.810	0.806	0.855	0.808	0.831	0.826
Na	0.042	0.062	0.066	0.076	0.089	0.088
Z	2.000	2.000	2.000	2.000	2.000	2.000
XY	1.978	1.990	1.995	1.972	1.974	2.000
Colour	Brown	brown	brown	pale green	pale green	
2V	47	48	51	55	59	
$z\wedge c$	43	n.d.	33	37	23	
β	1.728	1.714	1.719	1.708	1.706	
Mg	40.90	38.87	39.84	42.48	39.22	
Fe	13.21	16.87	13.37	12.23	15.00	
Ca	45.89	44.26	46.79	45.29	45.78	
% Al in Z	10	10.7	8.2	2.3	0.50	

P191-titanaugite from unanalysed basanite. P183-sodic augite from unanalysed Teide hyalophonolite. 26-after Carmichael (1967). All other analyses by W. I. Ridley.

The groundmass is largely composed of alkali feldspar laths in a felted or subtrachytic texture. Many of the flows contain patches of aegirine-augite ($z\wedge c$ 5—10°) a pale pink, kataphoritic ? amphibole, and deep red aenigmatite.

The Viejo-Teide phonolites may be better termed *hyalophonolites* as they are invariably very glassy (Fig. 5b). Broken and tabular anorthoclase phenocrysts, pale green sodic augite (2v 56—60, β—1.705, $z\wedge c$ 25—30°) and titanomagnetite are found in a pale yellow to deep brown glass. The pale brown glasses are packed with stellate alkali feldspar crystallites that define the flow structure. The early "pre-pumice" phonolites from Teide contain phenocrysts of deep brown amphibole and foxy red biotite.

Diagnostic Petrographic Features of each Rock Type

Basanites. Calcic labradorite and olivine (Fa 12—15) in groundmass.

Trachybasanites. Calcic andesine, and very rare olivine (Fa 15—25) in groundmass.

Plagioclase Phonolites. Potash-oligoclase, brown amphibole, and pale green pyroxene in groundmass.

Phonolites. Alkali feldspar, aegirine-augite, amphibole, aenigmatite, with or without feldspathoids, in groundmass.

Hyalophonolites. Pale yellow or brown glassy groundmass, and well defined phenocryst mineralogy.

Mineralogy

Olivines. Olivine is only encountered in the basanites, where it tends to be subordinate to pyroxene, and in the trachybasanites. In the basanites it varies from Fa 12—15 and in the trachybasanites from Fa 15—25. In the latter rocks it is commonly strongly iddingsitised. Two partial analyses gave MgO 45.73%, FeO 14.12%, (0—191 basanite) and MgO 38.5%, FeO 17.6% (0—7 trachybasanite). Comparison with the pyroxene analyses from these two rocks indicates the usual relationship of Fe enrichment in the olivine relative to the co-existing pyroxene (Muir and Tilley, 1961; Le Maitre, 1962).

Pyroxenes. Clinopyroxen eoccurs as a phenocrystal and groundmass phase in all the rock types. In the basanites the pyroxene may be colourless, or may have a pale green core and pinkish rim, or be pinkish brown throughout. Pale brown pyroxenes characterise the trachybasanites and are often complexly zoned. Hourglass structure is moderately common in the microphenocrysts. Pale green clinopyroxene phenocrysts are found in the plagioclase phonolites and phonolites, whereas strongly pleochroic green pyroxene is restricted to the groundmass of the microcrystalline phonolites.

The chemical compositions, structural formulae, and optical properties of some unzoned phenocrystal pyroxenes are found in Table 1. In addition microphenocrysts P8, P17, from two crystalline phonolites were partially analysed by atomic absorption methods; (P8). Fe_2O_3 13.60%, MnO 0.89%, MgO 9.10% CaO 21.59%, Na_2O 1.65%; (P17). Fe_2O_3 18.71%, MnO 0.97%, MgO 5.71%, CaO 20.62%, Na_2O 1.75%.

Titanium and aluminium rich pyroxenes characterise both the basanites and trachybasanites. P7 is particularly rich in titania, resulting in the incorporation of Ti in the Z site in the structural formula, to balance the low Si and Al. In all the other pyroxenes only Si and Al are found in tetrahedral coordination. The trend of differentiation is towards a decrease in both Al and Ti in the structure accompanied by an increase in Mn and a slight increase in Na. From P8, P17 it is evident that the trend is towards more iron enrichment rather than soda enrichment.

Surprisingly little compositional variation is evident in the pyroxenes that crystallise during the descent from basanite towards phonolite, even though fractionation results in considerable variations in MgO, CaO, Fe (total), and Na_2O in the rock series itself. It is only in P8, P17 that any decrease in MgO, CaO

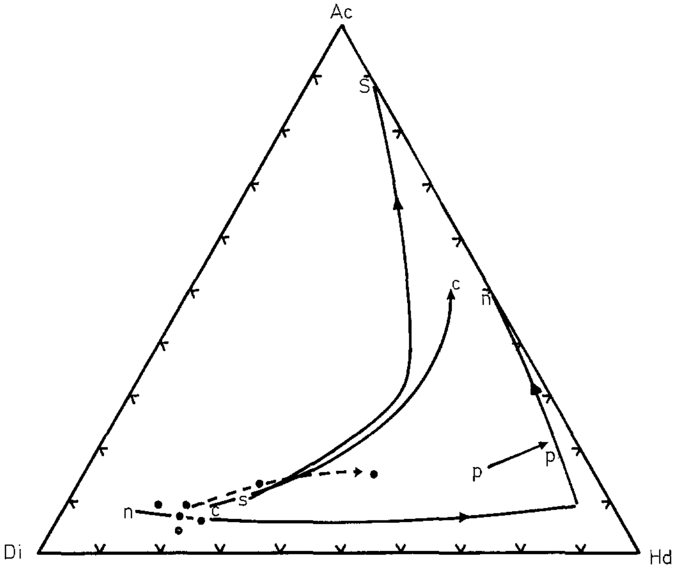

Fig. 6. Trend of crystallisation of pyroxenes in the system Ac-Jd-Di-Hd. *n* Nandawar trend (Abbott, 1969), *p* pantellerite trend (Carmichael, 1962), *s* Sakhalin trend (Aoki, 1964), *c* Cantal trend (Varet, 1969)

is noticeable, and only in the groundmass pyroxenes of the phonolites that any appreciable variation occurs.

Relative enrichment of the pyroxene in the acmite molecule only occurs when Na^+ and Fe^{3+} are concentrated sufficiently in residual liquids to replace Ca^{2+} and Fe^{2+} respectively (Le Maitre, 1962). In the Las Canadas volcanics this only occurs when the rocks are distinctly peralkaline. In the Teide hyalophonolites the relatively high FeO/Fe_2O_3 ratio (Table 4) suggests that these phonolites may not be sufficiently oxidised to concentrate Fe^{3+} so that only limited substitution of $Na^+ Fe^{3+}$ for $Ca^{2+} Fe^{2+}$ could occur. In the more crystalline phonolites eg. no. 8, the FeO/Fe_2O_3 ratios are systematically lower than the hyalophonolites and the pyroxenes are subsequently more enriched in $Na^+ Fe^{3+}$. Nevertheless, the association of deep green pyroxene with aenigmatite, magnetite, and possibly kataphorite, even in the microcrystalline phonolites, indicates the low PO_2 under which the residual liquids crystallised. This is also indicated from the trend of crystallisation of the rocks (Fig. 10) and the pyroxenes in the system (Ac + Jd)-Di-Hd (Fig. 6). The trend is in marked contrast to that of pyroxene crystallisation under high PO_2 conditions (Aoki, 1964), but is also unlike pyroxene crystallisation under very low PO_2 (Le Maitre, 1962; Abbott, 1969). It seems likely that trends within the system (Ac + Jd)-Di-Hd are at least partly dependent on the overall chemical characteristics of the rock suite as well as partial pressure.

Since only phenocrysts have been examined, the trend in Fig. 6 would probably be extended by the addition of the groundmass pyroxenes from the phonolites. Exactly what direction the extension would take remains unresolved. There are two possibilities, either a movement towards the pantelleritic pyroxenes of

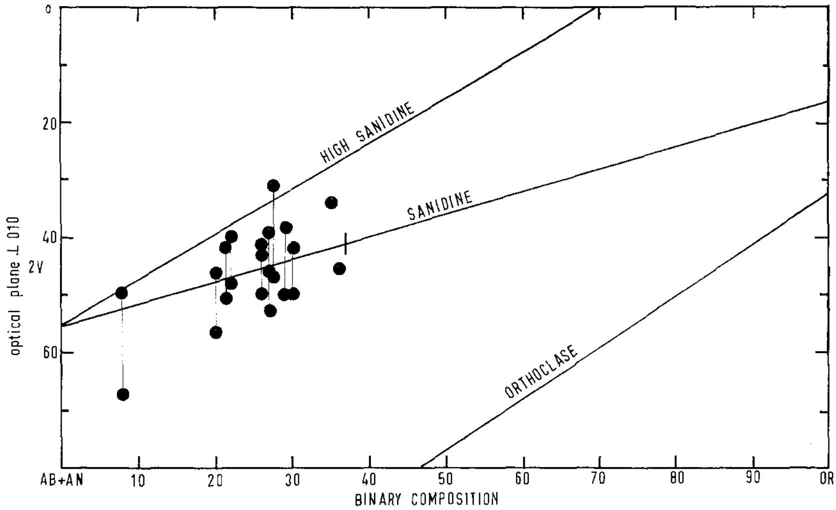

Fig. 7. Binary compositions and structural states of some Las Canadas anorthoclases, after Tuttle (1952)

Carmichael (1962) if the PO_2 remained constantly low or roughly parallelling the Cantal trend of Varet (1969) if there was an increase in PO_2 during the final stages of crystallisation. If the trend is partly composition dependent then the latter direction might be favoured.

Feldspars. The trachybasanites and plagioclase phonolites contain numerous phenocrysts of plagioclase feldspar, commonly found in glomero-phyric patches. The high structural state of seven plagioclases examined by X-ray diffraction is indicative of the volcanic environment in which they are found. Partial chemical analyses of andesine phenocrysts from trachybasanites showed a range of K_2O values from 0.65 to 0.94% and Sr values from 2,100 to 4,000 p.p.m. The enrichment of Sr in the plagioclase structure is indicated by the Sr (feldspar)/Sr (rock) ratio of 1.8—3.9 in the trachybasanites, but enrichment is less marked in the plagioclase phonolites where the ratio falls to 1.2.

Alkali feldspar occurs in the groundmass of the plagioclase phonolites and as a phenocrystal and groundmass phase in the phonolites. Intratelluric crystallisation of alkali feldspar in the phonolites is suggested by the patchy extinction and frequent rims of untwinned alkali feldspar surrounding finely twinned or cross-hatched twinned cores. The Or contents of 19 specimens were determined using the 2Θ separation of the $20\bar{1}$ peak from the $10\bar{1}0$ peak of a quartz standard (Orville, 1957). 6 specimens proved to be unmixed, but only A24, A17, both from coarsely crystalline phonolites, gave a good separation of the sodic and potassic peaks, which indicated approximate compositions of Or 80 and Or 8 for the two unmixed phases in both samples. Heating at 900° C for 24 hours produced a single phase composition of Or 36—37. The Or values, in combination with the optically determined 2V measurements, show the high structural state of all the specimens (Fig. 7), and all lie well within the anorthoclase field.

Partial chemical analyses of seven feldspars for K_2O, Na_2O, CaO, Ba, and Sr (Table 2) confirm the ternary nature of these alkali feldspars, which should be classed as anorthoclases. A 10 is a lime anorthoclase, but the rest contain less than 7.3% An. Plotted in the system An-Ab-Or the anorthoclases generally trend towards the low temperature region with increase in differentiation index, and the trend is similar to that predicted from experimental work (Tuttle and Bowen, 1958) for a series derived by fractional crystallisation. Sr. is much lower in the anorthoclases than in plagioclases from the more basic rocks but the concentration factors are systematically much higher in the anorthoclases. Ba is more noticeably concentrated in the anorthoclases, with Ba (feldspar)/Ba (rock) ratios varying from 3.1 to 8.9 in the Teide phonolites, but falling as low as 2.8 in some of the Vilaflor phonolites.

The cell parameters of five anorthoclases from Teide were also determined, and are shown in Table 2. An attempt to measure the cell parameters of A 24. A 17 proved impossible because of the poor resolution of the 111, $1\bar{1}1$, $\bar{1}12$, $11\bar{2}$ peaks

Table 2. *Partial chemical analyses and cell parameters of anorthoclases*

	A24	A17	A44	A40	A45	A46	A41	A50
CaO	0.60	0.31	1.50	2.62	0.98	0.92	0.77	0.44
Na_2O	7.15	7.58	7.94	7.82	8.13	7.95	7.90	7.36
K_2O	6.28	5.94	4.41	3.81	4.59	5.21	5.13	5.95
BaO	0.05	0.04	0.30	0.41	0.43	0.11	0.18	—
SrO	—	—	0.07	0.12	0.03	—	—	—
Or	36.94	34.84	25.64	22.14	26.96	29.95	30.06	35.25
Ab	60.23	63.64	67.05	65.08	68.22	65.60	66.16	62.42
An	2.83	1.52	7.31	12.73	4.82	4.45	3.78	2.22
Cn	0.10	0.10	0.70	1.00	1.10	0.20	0.40	—
Sf	—	—	0.10	0.30	—	—	—	—

BaO, SrO from spectrographic determinationd for Ba and Sr. Feldspar components (Or, Ab, An) recalculated to 100% without Cn and Sf. All specimens from analysed phonolites in Table 4.

	BTB-8	FR-1					
a	8.211	8.228	8.271	8.246	8.277	8.294	8.292
b	12.910	12.915	12.949	12.921	12.950	12.951	12.962
c	7.129	7.127	7.147	7.136	7.145	7.150	7.149
α	92.66	92.60	91.78	92.46	91.72	91.46	91.40
β	116.35	116.30	116.30	116.39	116.30	116.31	116.31
γ	90.23	90.29	90.19	90.31	90.23	90.14	90.16
a*	0.136	0.136	0.135	0.135	0.135	0.135	0.135
b*	0.078	0.078	0.077	0.077	0.077	0.077	0.077
c*	0.157	0.157	0.156	0.156	0.156	0.156	0.156
α^*	86.91	86.96	87.93	87.11	87.96	88.30	88.36
β^*	63.60	63.65	63.65	63.57	63.63	63.68	63.68
γ^*	89.41	88.40	88.91	88.44	88.89	88.12	89.13
V	676.10	677.90	685.70	680.40	686.20	688.20	688.70

BTB-8, FR-1 are from Boudette and Ford (1966). Cell edge measurements in Å, cell angles in degrees. Standard errors: a —0.005, b —0.003, c —0.003, α —0.003, β —0.05, γ —0.02, V-1.00, α^* —0.04, β^* —0.03, γ^* —0.04.

Analyses and cell refinements by W. I. Ridley, using a least squares program by Burnham 1962, modified for Fortran IV by M. T. Frost.

even after heat treatment for several days. This may be due to the structural closeness of both these specimens to monoclinic symmetry. All the anorthoclases studied showed some variation in cell parameters with chemical composition. In particular a marked decrease in cell volume accompanies an increase in Ca content, due to decrease in all three crystallographic axes. The most calcic anorthoclase A40 is transitional in cell size to the calcic anorthoclases described by Boudette and Ford (1966). Binary and ternary compositions estimated from the systematic variations in cell parameters (Mackenzie and Smith, 1956; Carmichael and Mackenzie, 1964) are compared to those from chemical data in Table 3. The largest error is in the estimated composition of A40, which confirms the earlier prediction of Boudette and Ford op. cit. concerning more calcic anorthoclases.

Table 3. *Comparison of anorthoclase compositions from chemical and X-ray data*

		A 44	A 41	A 40	A 45	A 46	BTB-8	FR-1
1	Or	25.6	30.0	22.1	26.9	29.9	15.7	16.8
	Ab	67.1	66.2	65.3	68.2	65.6	74.2	64.8
	An	7.3	3.8	12.6	4.9	4.5	10.1	18.4
2	Or	25.0	30.0	18.5	26.0	31.0	14.0	17.0
	Ab	72.4	66.6	72.3	71.0	64.3	83.8	69.6
	An	2.6	3.4	9.2	3.0	4.7	2.2	3.4
3	Or	25.0	30.0	18.5	26.0	31.0	14.0	17.0
	Ab	73.8	68.8	80.3	71.6	63.6	84.3	70.2
	An	1.2	2.2	1.2	2.4	3.4	1.7	12.8
4	Or	25.0	30.0	18.5	26.9	31.0	14.0	16.8

1 = Ternary compositions from chemical analyses.
2 = Ternary compositions from α^* and γ^* data, after Mackenzie and Smith (1956).
3 = Ternary composition from cell volume data, after Carmichael and MacKenzie (1964). BTB-8, FR-1 from Boudette and Ford (1966).
4 = Binary compositions from $20\bar{1}$—$10\bar{1}0$ (Quartz) after Carmichael and MacKenzie (1964).

Petrochemistry

A representative suite of rocks from Las Canadas were analysed for major elements by classical techniques and for trace elements by optical spectrography and X-ray fluorescence. Major element data for Vilaflor volcanics, Viejo and Teide volcanoes are shown in Table 4 and element variations in Fig. 8.

Major Element Variation. The basic volcanics found in Las Canadas are strongly undersaturated, and closely resemble the voluminous basanites analysed from other parts of Tenerife (Hausen, 1956; Fuster *et al.*, 1968), and the Canary Islands generally. The strong development of normative nepheline is characteristic of the entire alkaline assemblage, although modal feldspathoids are restriced to a few of the phonolites.

In addition, the suite is strongly sodic, giving an Na_2O/K_2O ratio approaching 2:1 in the phonolites, and distinguishes the Las Canadas volcanics from those on many other oceanic islands (Fig. 9). Excess of alkalis over alumina in some of the phonolites leads to the production of normative acmite and sodium metasilicate,

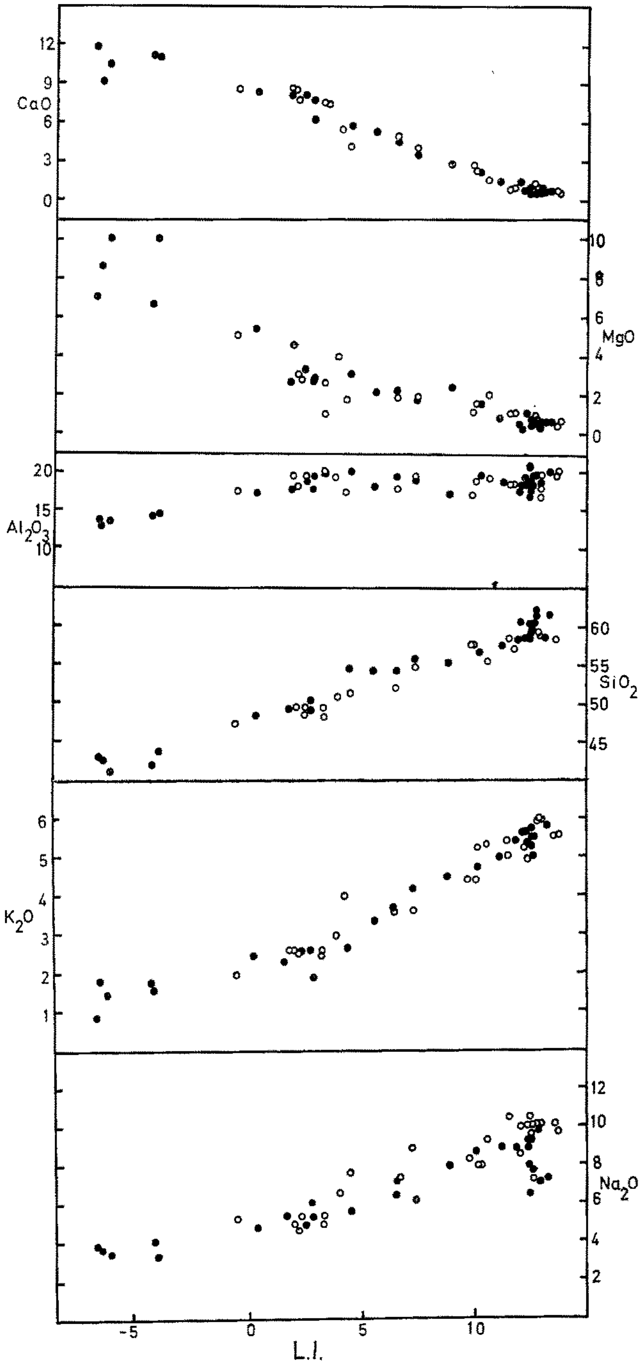

Fig. 8. Variations in selected major oxides. *L. I* Larsen Index. Solid dots, Vilaflor volcanics, open circles, Viejo and Teide

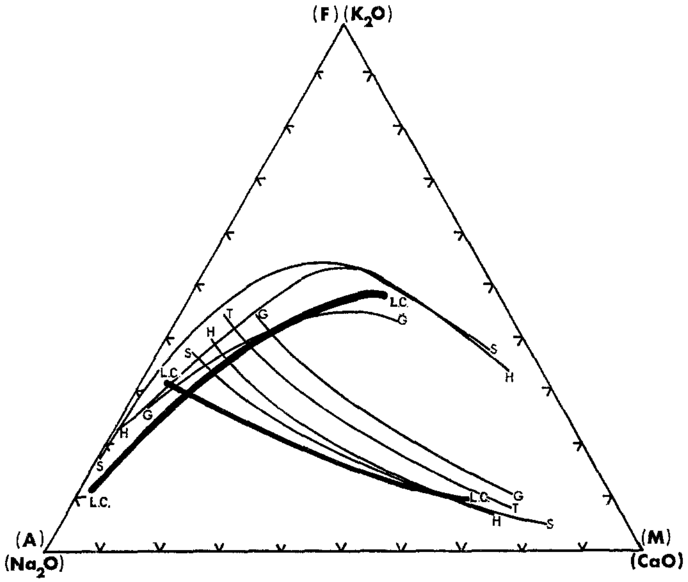

Fig. 9. Combined F-M-A and K_2O-Na_2O-CaO ternary diagram showing trend of differentiation of volcanics from some oceanic islands. *s* St. Helena (Baker, 1969), *H* Hawaiian alkaline trend (Macdonald and Katsura, 1964), *G* Gough Island (Le Maitre, 1962), *T* Tristan da Cunha (Baker *et al.*, 1964), *L. C.* Las Canadas volcanics

which may be modally represented by aegirine-rich groundmass pyroxene and aenigmatite.

The major element variations of the Vilaflor and Viejo/Teide volcanics are generally similar, although the Quaternary volcanics are somewhat more undersaturated, a point dealt with at a later stage. In all the rocks differentiation leads to enrichment in alkalis, an increasing Na_2O/K_2O ratio, and depletion in CaO, MgO, TiO_2 and total iron. The FeO/Fe_2O_3 is very variable for the Vilaflor volcanics, but only decreases noticeably in some of the highly differentiated phonolites. The ratio for the Viejo/Teide volcanics remains remarkably constant throughout the differentiation sequence. Mineralogically the elemental variations are reflected in the progressively more sodic and potassic nature of the crystallising feldspar, the slightly increased fayalite composition of the olivine during its curtailed period of crystallisation, gradual decrease in the amount of titanomagnetite, and in the slight change in composition of the pyroxenes.

The sudden increase in Al_2O_3 in the trachybasanites largely reflects the high proportion of modal plagioclase in the flows, but high Al_2O_3 also persists in some plagioclase phonolites and phonolites that contain relatively few phenocrysts. The situation therefore arises where the highly sodic phonolites are only mildly peralkaline (the peralkalinity index never exceeds 1.2) or even meta-aluminous because of the high Al_2O_3 values.

Trace Element Variation. The trace element abundances are typical of an alkaline volcanic suite, with even the most basic rocks containing more Zr, Nb, Rb, Sr, than their tholeiitic equivalents. *Ba* shows a gradual increase from 250—450 in the basanites to 1,500 p.p.m. in some of the Vilaflor phonolites. The Teide phonolites show rapid depletion of Ba to 70 p.p.m. following the onset of alkali feldspar crystallisation. *Sr.* From 1,000—1,450 p.p.m. in the basanites Sr remains rather constant through the intermediate stages, but is rapidly depleted to less than 40 p.p.m. in some of the phonolites. This would be consistent with the high distribution factors in some of the anorthoclases. *Rb.* From an initial value of 20—50 p.p.m. in the basanites, Rb rises slightly in the Vilaflor intermediate rocks to 100 p.p.m., then to 180 p.p.m. in some of the phonolites. In other phonolites it appears to be rapidly depleted below the limit of detection. In the Viejo intermediate rocks Rb is constantly below 100 p.p.m. rising to 200 p.p.m. in the phonolites. *Nb.* Gradually rises from 50—80 p.p.m. in the basanites to about 300 p.p.m. in the phonolites, with no evidence of depletion. *Zr.* From 600 p.p.m. in the basanites Zr rises gradually through the intermediate stages to 1,100 p.p.m. in some of the phonolites. Again their is no evidence for depletion of this element in any of the phonolites.

Ba/K. Significant amounts of Ba are usually captured by K-bearing minerals. This is indicated by the Ba/K ratio which remains constant up to the phonolitic stage, but decreases rapidly to almost zero once a K-bearing feldspar begins to crystallise.

Sr/Ca. This ratio shows a gradual increase from 15 in the basanites to 45—50 at the beginning of the phonolitic stage, then decreases rapidly to 5. Crystallisation of plagioclase alone cannot account for the observed variation, since it should result in a *depletion* of Sr in the liquid relative to the plagioclase, if large amounts of plagioclase crystallise. In the basic and intermediate stages the plagioclase is accompanied by a calcium-rich clinopyroxene which does not remove Sr from the liquid. This is considered to play a major part in the concentration of Sr in the intermediate stages of differentiation (Berlin and Henderson, 1968).

Variations in Chemical Composition with Time

Ridley (1969) has shown that the oldest volcanics in Las Canadas are exposed in the walls of the semicircular caldera. The Lower Canadas Series (Fuster *et al.*, 1968) appears to have largely erupted from fissures, but two well-defined centres of activity are exposed in the eastern part of the caldera wall, one of intermediate composition (Las Pilas volcano) lying above an older phonolitic centre.

The Quaternary succession indicates that the Viejo/Teide flank centres largely post-date all except the latest Teide phonolite flows and Ridley (1969) suggests that the flank activity was roughly synchronous with the formation of the Teide pumice field that directly underlies the latest Teide phonolites. In addition, the Sandiago volcanic field, that encroaches on the north-west flank of Viejo appears to be relatively recently formed, but older than the 1798 flank activity from Viejo.

Quite well defined geochemical features can be linked with the time relationships suggested above. The phonolites erupted by the Las Pilas volcano are consistently more undersaturated, and more enriched in Ba and Rb than comparable phonolites elsewhere in the Vilaflor volcanics. They are also the only flows in Las Canadas that consistently contain phenocrysts of nosean and amphibole. Volcanics of

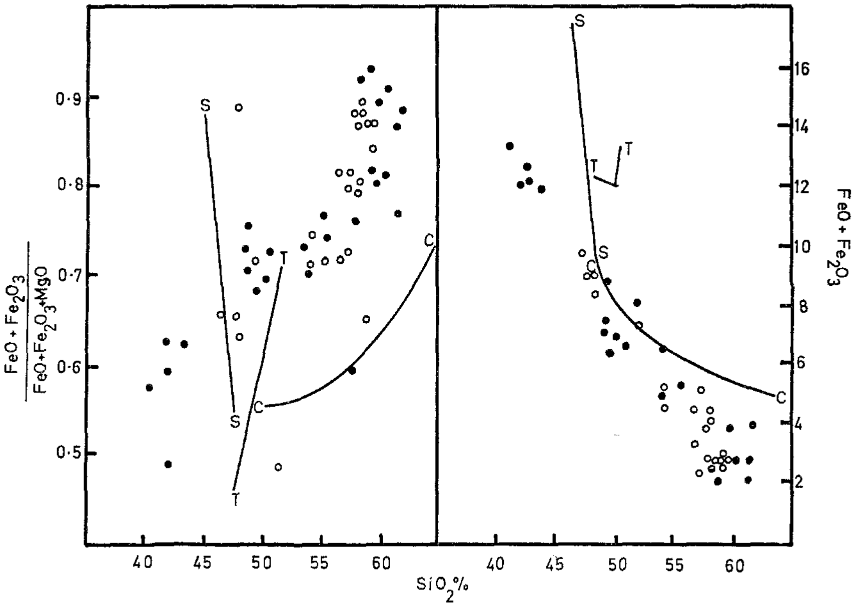

Fig. 10. Plot of $\frac{FeO + Fe_2O_3}{FeO + Fe_2O_3 + MgO}$, and $FeO + Fe_2O_3$ against SiO_2 for Las Canadas volcanics. Dots, Vilaflor volcanics; open circles, Viejo/Teide volcanics. *S* Skeargaard trend, *T* tholeiite trend, *C* Cascade trend (after Osborn, 1959)

trachybasalite and rarer plagioclase phonolite composition characterise the Lower Canadas Series, but phonolites and phonolitic trachytes are much more abundant in the Upper Canadas Series. The major and trace element abundances of flows at the top of the western part of the Las Canadas caldera indicate a return to intermediate volcanics during the final stages of evolution of the Vilaflor Complex. This corresponds to the Trachyte and Trachybasalt Series of Fuster *et al.* (1968). In particular these volcanics are enriched in Sr, and depleted in Ba, Rb and Zr relative to the underlying phonolites.

The Viejo/Teide volcanics are more strongly nepheline normative than comparable rocks in the Vilaflor Complex. For example, the final flows from these volcanoes are distinct phonolites with more than 10% normative nepheline, whereas those from the Vilaflor Complex are trachyphonolites with 0—10% normative nepheline. Variations in CaO, Ba, Sr, and Zr in the Teide phonolites (Fig. 11) suggests the influx of new magma during the late evolution of the volcano, or the tapping of a lower level of the magma resevoir. In particular, Ba shows a sudden uncharacteristic rise in the latest phonolites, although gradually depleted in earlier phonolites. This change in elemental bahaviour corresponds to the formation of the Teide pumice field, and, in addition, the low Ba values for the flank centre phonolites and the Teide pumice is consistent with their coeval formation.

The oldest flows that can be attributed to Teide (nos. 39, 40) are chemically transitional to trachybasanites, Hausen (1956) tabulates one analysis of a trachybasanite from near the summit of Teide which is similar to those erupted from

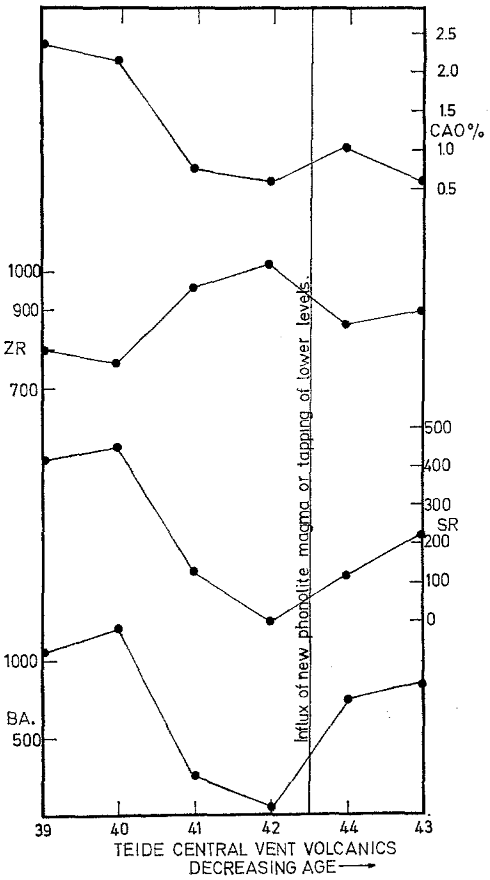

Fig. 11. Variations in selected trace elements, and CaO of Teide central vent volcanics

Viejo. It seems probable that phonolites only cap Teide and are underlain by intermediate volcanics of a composition similar to the Viejo flows. Of the more Recent flows, two have been analysed from the Sandiago volcanic field, whilst the 1798 Viejo flank flows and the 1705 Seite Fuentes flows have been analysed by Hausen (1956). The Sandiago volcanics range from trachybasanites to phonolites, apparently becoming more differentiated as the flows become younger. However there are too few analyses to be quite certain of this. The 1798 flow from Viejo is a trachybasanite, similar to the older trachybasanites erupted from the summit of Viejo. The 1705 flow is a basanite, one of a number erupted on Tenerife around this time.

The major conclusion to be drawn from these observations is that definite cycles of activity can be recognised structurally and chemically. The Lower Canadas Series and Upper Canadas Series together represent one cycle of intermediate to salic volcanism, with the beginning of a second cycle at the top of the Vilaflor Complex. The Viejo/Teide volcanics may be part of this second cycle or a third cycle. Again the chemical variation is from intermediate to salic types. The more recent volcanism appears unconnected chemically with the Teide volcanics, with a definite return to intermediate volcanics in the Sandiago field. The eruption of basic, intermediate and phonolitic magma from scattered vents in the Las Canadas area, within historic time, suggests the presence of recent, local pockets of magma at a high level within the superstructure of Tenerife. These local pockets could cool and differentiate effectively isolated from each other.

Petrogenesis

General Considerations. Each rock group, chemically and mineralogically defined, can be represented by aphyric rocks, and are thus assumed to have originally represented possible liquids. In addition, each group includes rocks containing abundant phenocrysts whose textural relationships suggests that the rocks are partial accumulates. Systematic variation in the chemistry of the aphyric volcanics, from the basanites through trachybasanites and plagioclase phonolites to phonolites indicates a genetic relationship between all these rock types. The abundance of accumulative rocks suggests that crystal settling has played an important part in determining the nature of the liquid descent from basanite to phonolite. The strong zoning of plagioclase and pyroxene in the basic and intermediate rocks provides a further mechanism whereby differentiation may have proceeded.

The major mineral phases encountered in the basanites and trachybasanites are olivine, clinopyroxene, plagioclase, and titanomagnetite. It is reasonable to assume that in the distinct periods of activity that built the Vilaflor Complex and the Viejo/Teide volcanoes, these four minerals have been of major importance in producing the observed chemical variations. Tilley *et al.* (1965) note the importance of elutriation of feldspar combined with the sinking of olivine and pyroxene in producing intermediate members of alkaline suites. The glomerophyric texture shown by the plagioclases and their ubiquitous zoning is indicative of their present non-equilibrium state and suggests they may have been inherited by floatation.

The restriction of olivine crystallisation to the basanites and trachybasanites may indicate a reaction relationship between this mineral and a strongly undersaturated liquid. Such a reaction has been observed in simple basalt systems (O'Hara, 1968) at high temperatures, but the addition of FeO, Fe_2O_3, alkalis, etc. in the natural systems may depress the reaction to lower temperatures. The observation of a similar restricted interval of olivine crystallisation in the Tristan da Cunha volcanics by Baker *et al.* (1964), but the presence of olivine throughout all the rock types on St. Helena (Baker, 1969) and Gough Island (Le Maitre, 1962) suggests that the reaction may be either composition dependent or markedly effected by PO_2, P_{H_2O} etc.

The Descent Basanite-Phonolite. In tholeiitic rocks the initial importance fo olivine in controlling the fractionation trend results in the formation of voluminous picritic rocks (Macdonald and Katsura, 1964; Katsura, 1967). By comparison, alkaline rocks commonly show a sparcity of picrites but an abundance of ankaramites. These reflect the importance of pyroxene as well as olivine in controlling the initial fractionation trend. Fig. 12 shows the trend of crystallisation of basanites from Tenerife in relation to the two principle phenocrystal minerals, olivine (Fa 12) and clinopyroxene. Both minerals are compositionally close to those found

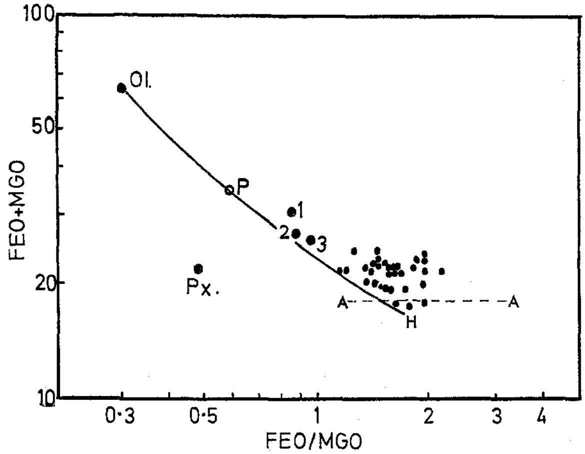

Fig. 12. Plot of FeO + MgO against FeO/MgO for some Tenerife basanites (small dots) and ankaramites (1, 2, 3) from the present study and from Hausen (1959). *Ol*, *PX* olivine and pyroxene, respectively, from porphyritic basanite 191 (unanalysed). *P* average composition of Hawaiian oceanites (Katsura, 1967), *A*-*A* Hawaiian trend controlled by olivine and pyroxene fractionation, *Ol*-*P*-*H* Hawaiian trend controlled only by olivine fractionation

in Hawaiian tholeiites but the trend is different to that on Hawaii because of the strong pyroxene component during the initial stages of crystallisation.

Neither of these minerals crystallise without the presence of titanomagnetite, so that liquids tend to be depleted in iron, calcium, and magnesium. The appearance of plagioclase as an important phase would further deplete liquids in calcium, and crystal settling accompanied by inefficient reaction of phases with liquid should result in final liquids enriched in alkalis and close to a cotectic equilibrium. The Viejo and Teide phonolites group closely around the ternary "phonolite minimum" in the system Qz-Ne-Ks (Fig. 13) and the alkali feldspars from these rocks also approach the binary feldspar minimum. Entry to this system for the Viejo/Teide rocks need not have been via trachytes (cf. Tristan da Cunha, St. Helena) since the intermediate liquids are themselves highly undersaturated. In fact neither trachytes nor trachyphonolites are found on the Viejo/Teide volcanoes.

In contrast the late derivitives of the Lower and Upper Canadas Series show a wider scatter in this system and are generally of trachytic or trachyphonolitic composition. They are derived, however, from intermediate rocks that are not as undersaturated as the Viejo/Teide intermediates. The problem still remains nevertheless of the derivation of the slightly undersaturated trachybasanites from a more undersaturated parent, and the derivation of liquids approaching true trachytes, from even mildly undersaturated intermediates. This is a problem not confined to Las Canadas, since residual trachytic liquids have been produced on both Tristan da Cunha and St. Helena from undersaturated basic and intermediate liquids. There is a possibility that some deviation from predicted fractionation trends may be brought about in the later stages of differentiation by vapour phase transfer of alkalis and silica. In Las Canadas occasional fault planes lined with silica testify to its presence as a free compound. The present fumerole activity at Teide and the presence of abundant pyroclastics throughout the history

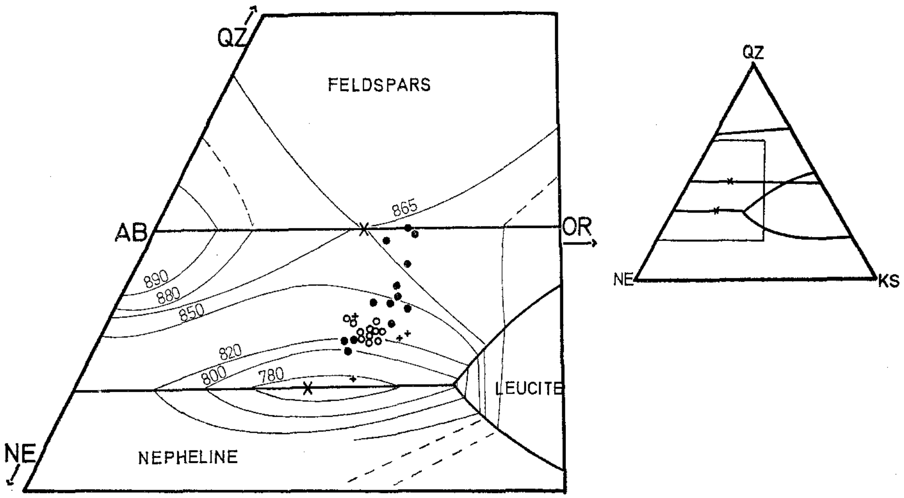

Fig. 13. Position of the Las Canadas residual volcanics (Thornton-Tuttle Index 80) in "Petrogeny's Residua System", *Qz-Ne-Ks*. Isotherms from Hamilton and Mackenzie 1965. Dots, Vilaflor volcanics; open circles, Teide volcanics. crosses, Viejo volcanics

of the Las Canadas volcanoes indicate the frequent presence of a gaseous phase whereby transfer of materials may have taken place.

The Development of Peralkalinity in the Teide Phonolites. Although many of the phonolites in Las Canadas remain meta-aluminous, the Teide phonolites in particular are commonly peralkaline. This is defined as an excess of alkalis over alumina that results in the appearance of acmite and sodium metasilicate in the norm and aegirine-rich pyroxenes and aenigmatite in the mode. In the few peralkaline phonolites from the Vilaflor volcanics the crystalline groundmass contains both of these minerals, but in the Teide phonolites the excess alkalis remain occult in the glass.

The early phonolites erupted from Teide were meta-aluminous (Table 4), followed by phonolites that became progressively more peralkaline. These phonolites all contain anorthoclase as the dominant phenocrystal mineral (Table 7). The importance of this mineral in the development of peralkalinity has been discussed by Bowen (1945), Bailey and Schairer (1964), Nichols and Carmichael, 1969) and Abbott (1969). The data from Table 7 indicate that 1. The meta-aluminous types have crystallised an anorthoclase more calcic than might be inferred from the normative feldspar components of the host rock. 2. Calcic anorthoclase also occurs in the peralkaline types even though no anorthite appears in the norm. 3. The K_2O/Na_2O ratio of the feldspar compared to that of the rock, is lower in the meta-aluminous types and higher in the peralkaline types. This is confirmed-by the alkalis ratio of two groundmass glasses (Table 7).

These observations indicate the importance of the "plagioclase effect" in producing peralkalinity in the Teide phonolites. It is initially most noticeable in the meta-aluminous types, but is still evident once peralkalinity has been attained. In addition, the "orthoclase effect" of Bailey and Schairer (1964) is evidently

Table 4. *Chemical analyses and Norms of Las Canadas Volcanics*

Lower Canadas series (Eastern caldera succession)

	1	2	3	4	5	6	7	8	9	10
SiO_2	41.15	42.57	42.64	43.77	48.83	49.14	49.19	49.85	54.17	55.51
Al_2O_3	13.27	12.83	13.85	14.30	18.70	17.80	19.57	19.12	19.14	17.04
TiO_2	4.40	3.36	4.30	4.01	2.43	2.67	2.50	2.36	1.88	1.93
FeO	9.01	8.99	7.90	7.56	3.12	1.93	4.54	5.16	2.22	4.07
Fe_2O_3	4.69	3.46	4.61	4.30	4.19	7.13	2.84	2.77	2.87	2.49
MnO	0.18	0.19	0.20	0.20	0.14	0.15	0.18	0.18	0.17	0.23
MgO	10.07	13.19	8.63	7.03	2.85	2.77	2.69	3.34	2.18	2.25
CaO	10.50	8.94	11.86	11.03	7.92	7.63	8.36	8.10	4.48	2.75
Na_2O	3.69	3.82	3.96	3.41	5.34	5.26	5.08	5.01	7.21	8.13
K_2O	1.55	1.83	0.91	1.66	2.52	1.96	2.63	2.59	3.69	4.45
P_2O_5	0.80	0.58	0.81	1.15	0.88	0.64	0.90	0.60	0.44	0.40
H_2O	0.69	0.52	0.38	0.69	2.11	2.63	0.71	0.85	0.61	1.06
H_2O	0.21	0.17	0.15	0.28	1.22	0.69	0.87	0.44	0.22	0.17
Total	100.21	100.45	100.20	99.39	100.25	100.40	100.06	100.37	99.28	100.48
OR	9.16	10.82	5.38	9.81	14.89	11.59	15.55	15.31	21.81	26.30
AB	5.32	4.18	10.74	15.95	30.91	36.65	27.86	27.88	37.16	33.12
AN	15.07	12.46	17.33	18.82	20.55	19.18	22.83	22.04	8.97	—
NE	14.03	15.24	12.33	6.99	7.73	4.26	8.19	7.86	12.98	16.12
DI	25.29	22.40	28.70	22.59	8.81	10.32	10.22	1.48	8.19	8.99
OL	13.43	21.92	8.46	7.75	2.11	1.48	2.88	4.63	1.65	3.90
MT	6.80	5.02	6.68	6.23	3.47	—	4.12	4.02	4.16	1.00
IL	8.35	6.38	8.17	7.61	4.61	4.39	4.75	4.48	3.57	3.66
AP	1.89	1.37	1.91	2.71	2.08	1.51	2.12	1.42	1.04	0.94
AC										5.20
NS										
Larsen Index	−6.56	−6.98	−6.69	−4.65	1.42	1.26	1.07	1.71	6.84	9.00
D.I.	28.51	30.24	28.45	32.75	53.53	52.50	51.60	51.05	71.88	75.54
Co	50	60	40	30	20	20	20	—	—	—
Ni	10	300	60	50	10	—	—	—	—	—
Cr	200	400	70	50	—	—	—	—	—	—
V	300	250	250	300	200	100	100	100	70	—
Cu	80	70	—	50	—	20	20	20	10	—
Ba	350	250	450	300	700	500	550	600	750	1,550
Rb	—	20	50	40	80	50	70	70	60	150
Sr	1,400	1,000	1,100	1,400	2,000	1,350	1,600	1,800	1,600	870
Nb	50	70	70	50	90	70	60	70	110	280
Zr	500	350	450	500	550	550	750	750	850	670
Ce	125	117	×	×	×	160	158	150	204	206

Analyses 52, 53, from Hausen 1956. All other analyses by W. I. Ridley.
— not detected.
× not determined.

				Upper Canadas Series (Eastern caldera)			Lower Canadas Series (Western caldera succession)			
11	12	13	14	15	16	17	18	19	20	21
57.41	57.85	58.42	61.69	58.97	60.58	59.23	49.68	54.28	55.60	60.26
18.79	18.85	17.21	18.91	20.63	18.08	16.83	19.96	18.26	18.59	18.39
1.27	1.60	1.42	0.71	1.06	0.64	0.90	2.10	1.99	1.59	0.83
2.54	2.43	1.91	—	1.87	0.85	0.85	3.69	4.02	3.52	1.11
1.08	1.38	3.34	2.87	0.51	2.64	3.94	2.67	2.47	2.85	1.75
0.21	0.21	0.19	0.22	0.22	0.21	0.26	0.29	0.23	0.17	0.13
0.93	1.49	0.38	0.83	0.49	0.79	0.30	2.67	2.20	1.59	0.68
1.75	2.35	1.68	0.94	1.11	0.55	1.12	6.45	5.27	3.49	0.98
9.01	8.67	8.88	7.02	9.09	9.81	9.15	5.01	6.64	6.14	6.42
5.09	4.40	5.40	4.98	5.56	5.28	5.55	2.56	3.15	4.17	5.48
0.13	0.21	0.18	0.07	0.12	0.43	0.07	0.60	0.43	0.32	0.33
1.13	0.56	0.95	1.62	0.14	0.17	1.60	2.65	0.43	1.75	3.00
0.11	0.09	0.18	0.29	0.39	—	0.40	1.09	0.12	0.40	0.36
99.45	100.09	100.14	100.15	100.16	100.03	100.20	99.42	99.49	100.18	99.72
30.08	26.01	31.92	29.43	32.86	31.21	32.80	15.13	18.62	24.65	32.39
35.44	42.02	34.63	58.00	37.78	43.20	35.97	35.06	40.20	43.72	54.32
—	—	—	4.21	—	—	—	24.42	10.72	—	2.71
17.81	16.50	12.91	0.76	20.25	11.06	10.67	3.97	8.67	4.46	—
6.53	8.25	4.89	—	3.98	—	2.66	2.92	10.18	3.53	—
1.49	0.75	—	—	0.98	2.07	—	4.94	2.20	2.93	0.56
—	1.61	—	—	—	—	—	3.97	3.58	4.14	1.60
2.41	3.04	2.70	2.87	2.01	1.21	1.71	3.99	—	—	1.57
0.31	0.50	0.43	0.47	0.28	1.01	0.17	1.42	1.01	3.02	0.78
3.13	0.78	9.66	1.45	1.48	7.64	11.40	—	—	0.76	—
1.02	—	1.35	—	0.02	2.50	2.05	—	—	—	—
11.31	10.17	12.01	12.88	12.51	12.74	12.58	2.48	5.84	7.50	12.58
83.33	84.52	79.46	88.18	90.89	85.47	79.44	53.16	67.47	72.83	86.71
—	—	—	—	—	—	—	20	—	—	×
—	—	—	—	—	—	—	—	—	—	×
—	—	—	—	—	—	—	—	—	—	×
—	—	—	—	—	—	—	100	110	80	×
—	—	—	—	—	—	—	20	25	10	×
720	970	1,550	1,400	760	×	450	550	510	900	650
150	150	180	70	100	×	—	70	70	100	×
690	860	650	300	100	×	200	1,600	1,350	1,100	×
260	200	250	150	200	×	330	60	70	110	×
750	620	780	820	940	×	1,050	750	550	1,000	×
178	177	212	×	231	×	288	158	×	×	248

Table 4 (continued)

	Upper Canadas series (Western caldera)					Viejo central vent volcanics		
	22	23	24	25	26	27	28	29
SiO_2	60.43	61.60	62.08	50.66	51.41	47.17	48.00	48.12
Al_2O_3	18.09	19.97	16.32	19.18	17.34	17.32	17.77	20.05
TiO_2	0.47	0.84	0.98	2.22	2.69	3.32	2.76	3.30
FeO	0.68	0.69	0.07	4.18	3.60	6.82	6.20	7.31
Fe_2O_3	2.35	1.76	4.02	2.63	4.57	3.15	2.43	1.84
MnO	0.21	0.25	0.10	0.20	0.26	0.20	0.20	0.20
MgO	0.29	0.35	0.49	2.87	3.14	5.01	4.42	1.05
CaO	0.79	0.88	1.21	7.25	6.35	8.59	8.48	7.44
Na_2O	8.64	7.08	7.11	6.20	5.73	5.38	5.48	5.54
K_2O	5.62	5.84	5.45	2.58	2.67	2.04	2.36	2.56
P_2O_5	0.19	0.22	0.13	0.66	0.87	0.65	0.84	0.82
H_2O	1.55	0.13	1.80	0.78	1.02	0.69	0.31	0.93
H_2O	0.11	0.35	0.50	0.25	0.17	0.10	0.34	0.25
Total	99.42	99.96	100.26	99.66	99.82	100.44	99.59	99.41
OR	33.22	34.52	32.21	15.25	15.78	12.06	13.95	15.13
AB	42.62	52.35	53.61	30.64	39.04	21.44	27.36	27.52
AN	—	2.93	—	16.89	13.72	17.09	22.82	22.29
NE	10.37	4.09	—	11.82	5.11	13.05	10.30	10.48
DI	2.23	—	1.87	11.81	9.42	17.11	3.67	7.91
OL	0.55	0.61	0.25	2.66	2.42	6.53	10.44	4.06
MT	—	0.61	—	3.81	4.65	4.57	3.52	2.67
IL	0.89	1.59	0.36	4.21	5.11	6.30	5.24	6.27
AP	0.45	1.52	0.31	1.56	2.05	1.53	1.98	1.94
AC	6.80	—	5.77	—	—	—	—	—
NS	0.84	—	—	—	—	—	—	—
Larsen Index	12.13	13.39	12.83	3.00	4.70	−0.20	1.93	3.54
D.I.	86.21	90.96	85.82	57.71	59.93	46.55	51.59	53.13
Co	—	—	—	—	20	20	25	20
Ni	—	—	—	—	—	—	—	—
Cr	—	—	—	—	—	—	—	—
V	—	—	—	100	80	140	140	180
Cu	—	—	—	10	10	15	10	40
Ba	650	480	180	750	680	450	610	690
Rb	80	120	70	40	70	30	40	50
Sr	—	40	—	1,500	1,500	1,300	1,300	1,350
Nb	190	160	160	100	90	100	80	100
Zr	1,000	950	820	840	850	580	500	380
Ce	×	261	246	170	×	×	162	155

30	31	32	33	34	35	36	37	38
48.32	49.55	52.01	54.55	54.55	57.56	51.01	55.70	58.37
17.06	18.00	17.30	19.93	19.09	16.87	14.21	18.99	18.24
2.89	2.48	2.18	1.58	1.60	1.36	2.88	1.07	0.72
6.97	6.69	4.75	3.70	3.78	1.03	5.94	3.49	0.64
2.31	1.92	2.75	1.07	1.75	4.37	4.76	1.69	3.27
0.24	0.16	0.17	0.21	0.16	0.18	0.19	0.19	0.17
5.24	3.17	3.10	1.87	1.76	1.17	4.05	2.06	0.53
8.26	7.72	5.01	4.13	4.07	2.70	5.39	1.74	0.82
4.89	4.67	7.21	7.68	9.06	8.31	6.51	9.42	9.92
2.58	2.64	3.59	4.09	3.64	4.38	3.02	5.29	5.90
1.03	0.85	0.65	0.32	0.20	0.21	0.80	0.35	0.07
0.10	1.05	0.30	0.23	0.82	0.07	1.13	0.64	0.83
0.09	1.16	0.80	0.05	0.21	0.81	0.14	0.11	0.14
99.98	100.06	99.92	99.41	100.69	99.02	100.03	100.74	99.62
15.25	15.60	21.22	24.17	21.51	25.89	17.85	31.27	34.87
23.20	29.78	30.86	34.28	32.36	40.45	35.32	25.89	30.24
16.99	20.36	4.25	9.39	0.68	—	0.64	—	—
9.85	5.27	16.37	16.63	24.00	11.89	10.71	22.94	16.65
13.98	10.20	13.17	5.07	14.90	6.28	16.64	5.25	2.87
9.31	7.17	3.22	4.29	0.17	—	3.39	5.54	0.19
3.35	2.78	4.15	1.55	2.54	—	6.90	—	—
5.49	4.71	4.14	3.00	3.04	2.56	5.47	2.03	1.37
2.43	2.00	1.53	0.76	0.47	0.50	1.89	0.83	0.17
—					6.97		4.89	9.46
—							1.38	2.84
0.50	2.37	6.83	4.72	7.41	9.93	4.18	10.74	13.01
48.30	50.63	68.41	75.08	77.87	78.23	63.88	80.10	81.76
20	20	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
140	70	—	30	—	—	—	—	—
40	70	—	10	—	—	—		—
760	600	1,200	950	1,050	1,470	1,070	1,500	100
40	130	—	50	70	130	70	170	200
1220	1,660	990	1,030	1,590	900	800	500	—
60	70	160	120	90	250	110	240	580
490	500	400	700	770	600	330	660	1,150
×	×	148	162	162	158	125	155	201

Table 4 (continued)

	Teide central vent volcanics						Teide flank vol-	
	39	40	41	42	43	44	45	46
SiO_2	56.79	57.62	58.58	58.42	59.66	58.34	57.06	58.57
Al_2O_3	19.00	19.71	17.77	19.58	19.21	18.22	18.11	18.12
TiO_2	1.37	1.30	0.75	0.68	0.80	0.73	0.84	0.83
FeO	1.17	2.03	2.11	2.17	2.06	3.15	4.84	2.44
Fe_2O_3	2.68	1.63	2.63	0.68	1.14	0.99	0.03	2.01
MnO	0.15	0.15	0.16	0.25	0.05	0.19	0.22	0.19
MgO	1.44	1.32	0.47	0.39	0.45	0.99	1.01	0.98
CaO	2.51	2.41	0.96	0.76	0.73	1.17	1.16	0.88
Na_2O	7.96	7.95	10.23	10.13	10.13	10.68	9.36	10.18
K_2O	5.17	4.75	5.89	5.58	4.95	5.03	5.38	5.27
P_2O_5	0.23	0.14	0.07	0.07	0.13	0.09	0.07	0.07
H_2O	0.96	0.44	0.53	0.98	0.53	0.52	0.90	0.47
H_2O	0.21	0.14	0.17	—	0.10	0.16	0.08	0.12
Total	99.64	99.59	100.32	99.69	99.94	100.26	99.06	100.13
OR	30.56	28.02	34.81	32.98	29.20	29.73	31.80	31.15
AB	36.82	41.33	30.58	35.72	42.89	36.14	34.58	35.25
AN	0.85	4.10	—	—	—	—	—	—
NE	16.54	14.05	15.18	18.38	15.40	16.02	15.51	15.50
DI	7.73	5.48	3.67	2.84	2.36	4.42	4.55	3.27
OL	—	0.86	1.68	2.14	1.86	3.86	6.11	3.17
MT	0.29	2.36	—	—	—	—	—	—
IL	2.60	2.47	1.42	1.29	1.52	1.39	1.60	1.58
AP	0.54	0.33	0.17	0.17	0.31	0.21	0.17	0.17
AC	—	—	7.61	1.97	3.30	2.86	0.10	5.82
NS	—	—	4.49	3.22	2.48	4.92	3.70	3.65
Larsen Index	10.28	10,21	12.99	13.75	12.40	11.79	11.87	12.24
D.I.	83.92	83.40	80.57	87.08	87.49	91.89	81.89	81.90
Co	—	—	—	—	—	—	—	—
Ni	—	—	—	—	—	—	—	—
Cr	—	—	—	—	—	—	—	—
V	—	—	—	—	—	—	—	—
Cu	—	—	—	—	—	—	—	—
Ba	1,050	1,200	270	70	850	770	550	150
Rb	120	130	240	170	150	160	170	190
Sr	420	450	130	—	220	120	70	—
Nb	140	120	300	200	140	300	240	270
Zr	800	770	960	1,020	900	870	800	1,070
Ce	211	147	193	215	172	167	288	183

canics						
47	48	49	50	51	52	53
58.56	59.46	58.48	58.97	42.12	48.60	43.05
19.06	19.50	19.45	19.09	14.20	21.03	15.19
0.61	0.69	0.78	0.70	4.26	2.90	2.60
1.94	2.12	2.11	1.93	8.12	7.34	9.72
1.34	0.61	0.92	0.97	4.17	0.96	3.46
0.26	0.23	0.25	0.25	0.20	×	0.21
0.41	0.47	0.44	0.44	6.62	3.72	9.05
0.78	0.84	0.68	0.71	11.24	8.10	10.47
10.61	10.17	10.15	9.88	4.25	5.67	3.26
5.48	5.55	5.86	5.56	1.83	2.26	1.39
—	0.08	0.06	0.33	1.17	×	0.66
0.27	0.76	0.64	0.83	0.90	×	0.98
0.38	—	0.05	0.12	0.16	×	0.08
99.70	100.48	99.87	99.78	99.24	100.58	100.12
32.39	32.80	34.64	32.86	10.82	13.3	8.2
38.10	38.10	33.72	39.04	8.11	18.5	8.9
—	—	—	—	14.27	25.1	22.6
16.96	16.96	18.26	15.28	15.09	15.9	10.1
3.12	3.12	2.55	1.17	27.05	12.4	20.4
2.08	2.08	2.14	2.52	6.01	8.2	17.2
—	—	—	—	6.05	1.4	5.0
1.31	1.31	1.48	1.33	8.09	5.5	4.9
0.19	0.19	0.14	0.78	2.76		1.5
1.77	1.76	2.66	2.81			
3.41	3.41	3.59	3.06			
12.66	12.74	13.02	13.82			
84.76	87.85	86.60	87.17	34.02	47.7	27.1
—	—	—	—	30		
—	—	—	—	20		
—	—	—	—	—		
—	—	—	—	250		
—	—	—	—	60		
80	130	60	60	450		
170	180	170	190	—		
—	40	—	—	1,450		
200	170	200	170	80		
1,020	950	1,150	620	600		
×	202	222	208	152		

Table 5. *Localities and descriptions of analysed samples*

Sample	I.C.	Description and Locality
1	A 2285	Pyroxene-olivine basanite. Eastern extremity of Portillo escarpment. (377315).
2	A 2287	Pyroxene-olivine basanite. Portillo escarpment at El Portillo (377315).
3	A 2288	Aphyric basanite flow. 100 m. east of Los Infantes, Portillo escarpment (375316).
4	A 2289	Aphyric basanite dike cutting flow no 3. (375316).
5	A 2290	Pyroxene trachybasanite. 300 m above base of Portillo escarpment. (369313).
6	A 2291	Pyroxene trachybasanite flow below Topo de la Greita. Portillo escarpment at El Pasijiron. (370313).
7	A 2292	Pyroxene trachybasanite flow at La Angostura. (370313).
8	A 2294	Pyroxene trachybasanite above no 7.
9	A 2297	Plagioclase phonolite flow. 300 m above escarpment base (369313) between Topo de la Greita and El Pasijiron.
10	A 3000	Plagioclase phonolite flow 50 m above exposed base of Las Pilas volcano. (372316).
11	A 3001	Phonolite flow. Above no 10.
12	A 3002	Phonolite flow. Above no 11.
13	A 3003	Phonolite flow. Above no 12.
14	A 3012	Phonolite flow from centre below La Angostura (371314).
15	A 3004	Phonolite plug. Beneath Montana Guajara. Upper Canadas Series. (369310).
16	A 3010	Eutaxite glass. East of Topo de la Greita. Upper Canadas Series. (370314).
17	A 3005	Phonolite flow capping Las Pilas volcanics. (367303).
18	A 2293	Big-feldspar trachybasanite. 100 m west of Boca de Tauce. Lower Canadas Series. (376703).
19	A 2298	Plagioclase phonolite above 18. Lower Canadas Series. (367303).
20	A 2299	Plagioclase phonolite above 19. (367303).
21	A 3008	Phonolite dike. West of Mna. Guajara. Upper Canadas Series. (367309).
22	A 3009	Phonolite plug. Roques de Garcia. Upper Canadas Series (368308).
23	A 3011	Phonolite sill. Roques de Garcia. Upper Canadas Series (368308).
24	A 3013	Phonolite flow. West of Mna. Guajara. Upper Canadas Series (366309).
25	A 2095	Trachybasanite flow. Valley filling sequence 4 km west of Mna. Guajara. Upper Canadas Series or Trachyte and Trachybasanite Series. (366308).
26	A 2096	Trachybasanite. Montana Cedro. Trachyte and Trachybasanite Series. (369301).
27	A 3014	Trachybasanite underlying 1798 flow. Boca de Tauce-Sandiago road cutting. Viejo flow. (368303).
28	A 3015	Trachybasanite ropy lava. Viejo central vent flow. Boca de Tauce. (367303).
29	A 3016	Trachybasanite flow. Viejo south flank. (367304).
30	A 3017	Trachybasanite ropy lava. Beneath Mna. Cedro. Viejo central vent flow. (368302).
31	A 3018	Trachybasanite ropy lava. 0.5 km north of Roques de Garcia. Viejo central vent flow. (369307).

Table 5 (continued)

Sample	I.C.	Description and Locality
32	A3019	Trachybasanite flow. Road cutting Viejo west flank. (370302). (372304).
34	A3021	Plagioclase phonolite. S.E. wall of Viejo caldera. (372304).
35	A3022	Phonolite. Top flow, S.E. wall Viejo caldera. (372304).
36	A3023	Trachybasanite flow from scoria cone. Sandiago volcanic field. (372301).
33	A3020	Plagioclase phonolite. 70 m from base of Viejo summit caldera. S.E. wall.
37	A3024	Phonolite flow from scoria cone. Sandiago volcanic field. (372300).
38	A3025	Phonolite flow. Montana Blanco. Viejo flank vent. (373303).
39	A3031	Phonolite flow. Below eastern part of Las Canadas caldera. Teide central vent flow ? (372315).
40	A3026	Phonolite flow. Teide central vent flow on south flank. (372308).
41	A3029	Phonolite flow. Teide central vent flow on south-west flank. (369308).
42	A3028	Phonolite pumice. Teide central vent pumice. (374311).
43	A3030	Phonolite flow. Below El Piton. Teide central vent flow.
44	A3027	Phonolite flow. Post-pumice flow. Main road cutting. (371308).
45	A3032	Phonolite flow. Montana Majua. Tiede flank vent. (371310).
46	A3035	Phonolite flow. Montana Abejera. Teide flank vent. (378309).
47	A3034	Phonolite flow. Montana Blanca. Teide flank vent. (373310).
48	A3037	Phonolite flow. Montana Blanca (post-pumice flow) Teide flank vent. (373310).
49	A3033	Phonolite flow. El Tabonal (372311).
50	A3036	Phonolite flow. Montana Rajada. Teide flank vent. (373312).
51		Basanite. Capping eastern part of Las Canadas caldera. Post Viejo/Teide age ? (373316).
52		Trachybasanite. Chahorra flow. 1798 flank activity of Viejo (Hausen 1956).
53		Basanite. Seite Fuentes flow. 1705. (Hausen 1956).

I.C. = Reference no. refer to samples housed in The Dept. of Geology, Imperial College, London, S.W. 7.
Locality names and grid references refer to the 1:25,000 Cartografia Militar de Espana (1959).

inoperative in the meta-aluminous types but is observed once peralkalinity has been attained.

Plagioclase-rich intermediate volcanics are commonly observed in Las Canadas, but do no lead to Al_2O_3 depleted liquids, as suggested by Abbott (1969). Indeed the phonolites are remarkably aluminous and even though the rocks are strongly alkaline only mildly peralkaline volcanics are produced. There can be little doubt that the final development of peralkalinity resulted from processes operating near the final stages of fractional crystallisation, rather than in the intermediate stages.

Little analytical data is available for the development of peralkalinity in the Vilaflor volcanics. An analysis of the anorthoclase in rock no. 24 (Table 7), a meta-aluminous trachyte shows it to contain significant CaO. The groundmass of

Table 6. *Average analyses and C.I.P.W. Norms from Canary Islands*

	1	2	3	4	5	6
SiO_2	44.22	43.49	43.49	41.51	43.02	43.69
Al_2O_3	12.74	14.91	14.78	14.23	13.38	15.33
TiO_2	2.93	4.27	4.00	4.22	3.69	3.12
FeO	8.01	8.98	7.61	8.29	9.61	8.37
Fe_2O_3	4.11	2.64	4.93	4.93	4.12	4.49
MnO	0.14	0.14	0.14	0.16	0.18	0.17
MgO	11.85	8.24	7.18	8.44	9.38	7.51
CaO	10.86	11.49	11.13	12.05	10.77	11.09
Na_2O	3.05	3.07	4.00	3.07	2.98	3.41
K_2O	1.01	1.22	1.96	1.40	1.51	1.50
P_2O_5	0.61	0.28	0.60	0.28	0.63	0.69
H_2O	0.26	1.48	0.28	1.05	0.70	0.70
H_2O	0.15	—	0.13	0.49	0.22	0.03
Total	99.94	100.11	100.23	100.12	100.10	100.10
OR	6.1	7.2	11.6	8.3	8.9	8.9
AB	14.5	10.1	8.0	4.0	9.8	11.9
AN	18.6	23.3	16.6	20.9	18.7	22.1
NE	6.1	8.6	14.0	11.9	8.3	9.2
DI	23.7	25.6	27.5	29.4	24.6	22.8
OL	17.1	11.3	6.0	8.2	14.5	10.5
MT	5.8	3.8	7.1	7.1	6.0	6.5
IL	5.5	8.1	7.6	8.0	6.8	5.9
AP	1.8	0.7	1.4	0.7	1.5	1.6

1 = Average of 5 olivine basalts (basanites), Lanzarote. (Hausen, 1959).
2 = Average of 4 olivine basalts (basanites), Gomera. Bravo (1964).
3 = Average of 7 olivine basalts (basanites), La Palma. Fuster *et al.* (1952).
4 = Average of 5 olivine basalts (basanites), Anaga peninsula, Tenerife. Hausen (1956).
5 = Average of 3 pre-historic olivine basalts (basanites), Tenerife. Hausen (1956).
6 = Average of 3 historic eruptions, Tenerife. Hausen (1956).

Table 7. *Feldspar compositions and K_2O/Na_2O ratios for some peralkaline phonolites*

		40	46	50	45	44	41	24
	Peralk. Index	0.84	1.12	1.06	1.07	1.15	1.19	0.94
1	Or	22.1	29.9	35.3	26.9	25.6	30.0	36.9
	Ab	65.3	65.6	62.5	68.2	67.1	66.2	60.3
	An	12.6	4.5	2.2	4.9	7.3	3.8	2.8
2	Or	36.9	45.4	44.2	46.4	43.7	51.7	36.9
	Ab	57.7	54.5	55.8	53.6	56.3	48.3	63.0
	An	5.4	—	—	—	—	—	—
K_2O/Na_2O	Rock	0.60	0.51	0.56	0.47	0.58	0.58	0.76
	Feldspar	0.48	0.65	0.81	0.55	0.65	0.65	0.89
	Groundmass	0.68		0.48				

1 = Composition of analysed feldspar.
2 = Normative feldpar composition of analysed rock.
40 is the oldest Teide phonolite, 41 the youngest. 24 is a phonolite from the Upper Canadas Series.

this rock contains both a deep green pyroxene and aenigmatite that reflect its peralkaline nature. Since anaorthoclase is the only phenocrystal mineral, separation of it from the initial trachytic liquid must have produced peralkalinity in the residual liquid, now represented by the groundmass of the rock.

The Parental Magma in Las Canadas. Basic volcanics similar to those found in the eastern part of the Las Canadas caldera, or of similar ago to the flows from Viejo and Teide are abundant outside of the Las Canadas area. Basic volcanics in the Las Canadas area are of insignificant volume compared with intermediate and phonolitic rocks. However, it is considered that the intermediate and phonolitic rocks should be considered in the context of the amount of basic volcanics found on the island as a whole. From this point of view it is evident that magma of basanitic composition has been available for eruption over the time span that covers the subaerial growth of Tenerife.

In broader terms, the basanites found in Las Canadas are not only very similar to others found on Tenerife (Hausen, 1956; Fuster *et al.*, 1968), but are chemically similar to basanites on Lanzarote (Hausen, 1959), La Palma (Fuster *et al.*, 1952), Gomera (Bravo, 1965), Gran Canaria (Hausen, 1962), and Hierro (Fuster *et al.*, 1952). Some comparisons with basic volcanics on other Canary Islands, and with other Atlantic islands can be found in Table 8. Although some chemical differences do exist between the basanites on different Canary islands, for instance, in alkalis and titania content, it is nevertheless evident, that strongly undersaturated volcanics form extensive, and in some cases almost exclusive parts of the volcanic piles, and are thus considered to be parental to the intermediate and salic volcanics described here.

The abundance of ankaramitic flows on Tenerife, and the textural relationships within them suggests that pyroxene is the liquidus phase over a considerable temperature range during the initial crystallisation of basanite magma. Experimental data directly applicable to liquids of basanite composition are scarce. Green and Ringwood (1967) have shown that in an alkali olivine basalt (2.2% normative nepheline) aluminous clinopyroxene appears on the liquidus between 13—20 kb, but below 13 kb the liquidus phase is olivine. Similarly, at 1 atm olivine is the liquidus phase in a nepheline basanite (Tilley, Yoder, and Schairer, 1966), and below 18 kb in an hydrous olivine nephelinite (Bultitude and Green, 1968). When clinopyroxene is found as a liquidus phase at 1 atm in basanites it is accompanied by plagioclase (Tilley, Yoder, and Schairer, 1965).

The absence of plagioclase as a major phase in the Tenerife basanites, the observation of chrome spinel in some of the ankaramites and the aluminous nature of the clinopyroxenes in basanites compared to those found in trachybasanites, leads to the conclusion that the basanite magma began to crystallise at depths between 13—20 kb. Fractional crystallisation of clinopyroxene, followed by olivine and spinel during the ascent of the basanite magma would result in ankaramite flows at the surface enriched in Cr, Ni, Co and showing an intermediate pressure mineralogy, and modified basanite magma depleted in these trace elements and enriched in Ba and Zr. This is the observed pattern amongst the Las Canadas aphyric and porphyritic basanites.

In addition, some Tenerife basanites carry megacrysts of kaersutite. Similarly, xenoliths of clinopyroxene, kaersutite, Fe-Ti oxides, and apatite have been

Table 8. *Analyses of Tenerife kaersutite, pyroxene megacrysts and pyroxenes from basanites*

	1		2	2a	3	3a	4	4a	5	6	7
SiO_2	39.2	Ca	49	50	48	47	47	44	47.4	38.8	37.1
Al_2O_3	12.7	Mg	38	35	35	38	41	45	39.9	45.9	50.8
TiO_2	5.9	Fe	13	15	17	15	12	11	12.7	15.3	12.1
FeO	6.5	% TiO_2	2.2	3.1	1.9	1.1	2.2	1.3	2.1	1.9	0.7
Fe_2O_3	4.0										
MnO	0.1										
MgO	13.1										
CaO	12.4										
Na_2O	3.6										
K_2O	1.5										
H_2O	1.4										
Total	100.4										

1 = Kaersutite megacryst in basanite, Anaga peninsula, Tenerife, Analyst: W.I.R.
2, 2a = Core and rim, respectively of clinopyroxene associated with kaersutite in xenolith in basanite, Gran Canaria Frisch and Schmincke (1968).
3, 3a = As above.
4, 4a = Core and rim, respectively of clinopyroxene phenocryst in basanite, Gran Canaria. Frisch and Schmincke (1968).
5 = Phenocrystal pyroxene in analcime olivine theralite, Wilkinson (1966).
6 = Pyroxene megacryst in basanite. Binns (1969).
7 = Megacryst in analcime basalt. Binns (1969).

reported from basanites on Gran Canaria by Frisch and Schmincke (1968), and from Tenerife by Borley, Suddaby and Scott (1969). A Tenerife kaersutite megacryst from the Anaga peninsula on Tenerife, analysed by the author (Table 8) was slightly embayed and rimmed by a thin sympletic intergrowth of titanaugite and titanomagnetite, but was otherwise optically homogeneous. This feature, together with its close chemical correspondence to a basanite, suggests that the megacrysts may be of connate, rather than mantle origin.

Considerable importance has recently been placed on the role of amphiboles in alkali basalt genesis. Oxburgh (1964) and Nicholls (1965) suggest that amphibole could be an important mantle phase, and Mason (1968) has argued that partial melting of kaersutite bearing mantle could produce strongly undersaturated, titania-rich derivitives with the alkalis ratio of alkali basalts. Binns (1969), however, suggests that some kaersutites in basanites could be of connate, high pressure origin. On Gran Canaria kaersutite xenocrysts are intimately associated with clinopyroxene xenocrysts. Compared with the high pressure aluminium augites from Binns (1969) the latter contain significantly higher TiO_2, whereas the Gran Canaria pyroxenes are closely similar to pyroxenes from basanites (Table 8). If the kaersutite and pyroxene megacrysts from Gran Canaria have a similar origin, and this can be extrapolated to include the Tenerife kaersutites, it appears that a relatively shallow,connate origin would be consistent with their chemical features.

It is evident, however that amphibole is a common and important mineral in alkali basalt genesis or modification. Amphibole-bearing xenoliths have been reported from Tristan da Cunha by Baker *et al.* (1964), Le Maitre (1969), from

St. Helena by Baker (1969), and from the Gulf of Guinea islands by Fuster *et al.* (1954) as well as from the Canaries. The majority of occurrences in the Atlantic suggest that it is of connate origin, in which case it is unlikely to be important in the actual genesis of undersaturated liquids, but may be important in their subsequent modification.

Conclusions

1. The volcanic rocks of Las Canadas are chemically and mineralogically divisible into basanites, trachybasanites, plagioclase phonolites, and phonolites. Olivine appears only in the basanites and trachybasanites, after which stage it appears to have a reaction relationship with the liquid. Plagioclase crystallisation is suppressed in the basanites but is a major feature of the trachybasanites.

2. The smooth curves of variation of major and trace elements, the presence of glomerophyric flows at all stages of differentiation, and the close approach of the final residua to eutectic crystallisation, indicate that the descent from basanite to phonolite was achieved by fractional crystallisation.

3. Chemical and field evidence indicate a number of cycles of activity. Two cycles are represented or partly represented by the Vilaflor Complex flows exposed in the walls of the caldera in Las Canadas. The first cycle corresponds to the Lower Canadas Series and Upper Canadas Series, the second cycle to the Trachyte and Trachybasalt Series of Fuster *et al.* (1968). The Viejo and Teide volcanoes may be a continuation of this latter cycle or possibly the beginnings of a third. The recent activity along the linear Sandiago volcanic field is unrelated to the activity that built the Viejo-Teide volcanoes, and may again represent the beginning of another cycle. In all the cases the cycles are characterised by a gradual change to more phonolitic types as they progress.

4. The development of peralkalinity in the Teide phonolites is largely due to the crystallisation initially of calcic anorthoclase that removes calcium and aluminium from the liquids. Peralkalinity may then be enhanced, once peralkalinity has been attained by the crystallisation of a potassic feldspar from a progressively more sodic liquid.

5. The volumetric abundance of basanites on Tenerife, and on other Canary islands, and its relatively constant composition throughout the 20 m. yrs. of subaerial growth, suggest that it should be adopted as the parental material to the intermediate and salic rocks. Trace element data for the aphyric basanites and their close association with ankaramites is consistent with initial crystallisation of basanite magma during its ascent to the surface. The chemical features of kaersutite megacryst found in some basanite lavas on Tenerife, if considered along with similar amphiboles found with pyroxenes on Gran Canaria, indicate that they are of connate origin and may have played an important part in the modification of the basanite magma during its ascent to the surface.

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