Eur. J. Mineral.
1993, 5, 97-106

Phonolitic origin of Roque Nublo ignimbrites of Gran Canaria (Canary Islands, Spain) from clinopyroxene melt inclusion studies *

José MANGAS [(1)], Francisco José PEREZ-TORRADO [(1)], Dominique MASSARE [(2)] and Robert CLOCCHIATTI [(2)]

[(1)] Departamento de Geología, Facultad de Ciencias del Mar, Universidad de Las Palmas de Gran Canaria, 35017 - Campus de Tafira, Las Palmas de Gran Canaria, Spain

[(2)] Laboratoire Pierre Süe, Groupe des Sciences de la Terre, Centre d'Etudes Nucléaires, Saclay, F-91191 Gif-sur-Yvette Cedex, France

Abstract : The Roque Nublo non-welded ignimbrites — which are Pliocene in age (5-3.5 Ma.) — are characteristic deposits of the second magmatic cycle on Gran Canaria. They are very heterogeneous, with 30-50 % volume lithic fragments, 15-20 % mildly vesiculated pumice, 5-10 % phenocrysts and 30-40 % ash matrix. The juvenile materials (pumice fragments and ash matrix) are largely altered to zeolites.

A melt inclusion study using microthermometric and electron-microprobe analyses was carried out on clinopyroxenes from Roque Nublo ignimbrites. The chemical composition of melt inclusions indicates that the original melt prior to the eruptions that formed the ignimbritic Roque Nublo deposits was phonolitic in composition.

Key-words : melt inclusions, clinopyroxenes, phonolites, Roque Nublo ignimbrites, Gran Canaria (Canary Islands, Spain).

Introduction and geological setting

The Canaries Archipelago, which comprises seven large islands and several islets, is situated in the Atlantic Ocean between latitudes N 28° and N 29° (Fig. 1). In geotectonic terms, these islands are located on the passive continental margin of the African plate. Gran Canaria is the central island of the Archipelago.

The geological build-up of Gran Canaria began during the Miocene with an episode of submarine volcanism of which little is known. The subaerial stage of development can be divided into three main magmatic episodes, called Cycle I or Old in the Miocene (14 to 8.5 Ma.), Cycle II or Roque Nublo in the Lower Pliocene (5 to 3.5 Ma.) and Cycle III or Recent in the Plio-Quaternary (2.8 Ma. to present) (Schmincke, 1976 ; McDougall & Schmincke, 1976-77 ; Araña & Carracedo, 1978).

The magmatic Cycle II began with the emission of small amounts of nephelinitic lava in the south of Gran Canaria. Later, from 4.4 to 3.5 m.y., the locus of volcanic activity shifted toward the central part of the island (Hoernle, 1987). During this later period, a considerable quantity of lava was erupted (basalt, basanite, tephrite and phonolite flows), while pyroclastic deposits — knowns as the Roque Nublo agglomerates or breccias — were emplaced and endogenous plugs of phonolitic composition were in-

* This paper is a contribution presented at the ECROFI meeting, Florence, Italy, 10-12 April 1991. The other contributions are presented in Eur. J. Mineral., vol. 4, n° 5.

0935-1221/93/0005-0097 $ 2.50

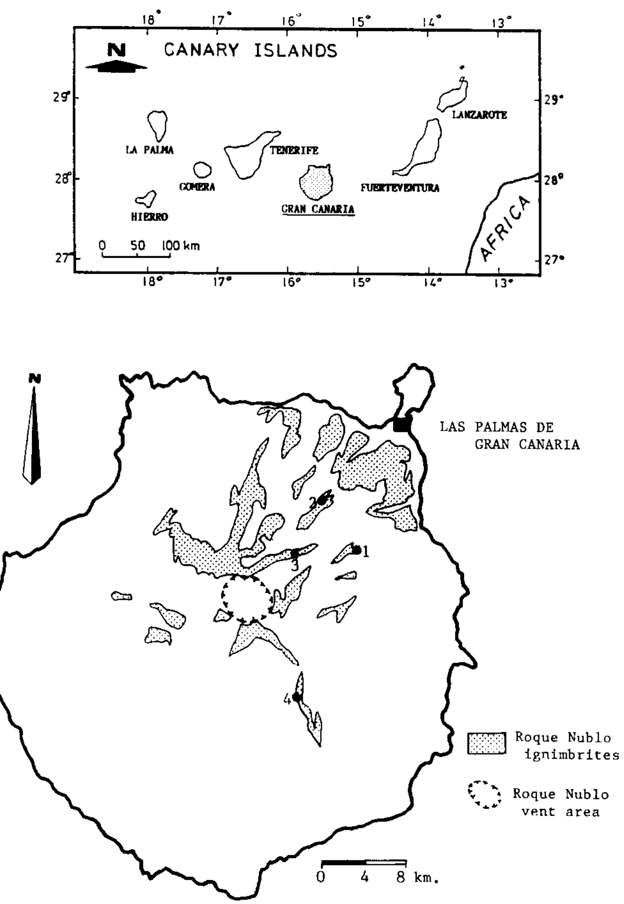

Fig. 1. Geographical location of the Canary Islands and geological sketch map of the Roque Nublo ignimbrites on Gran Canaria, with the location of the samples selected for this study (1 : sample TA 11 ; 2 : sample TD-1 ; 3 : sample SBP-4 and 4 : sample EP-3).

truded (Anguita, 1972 ; Schmincke, 1976, 1990 ; Brey & Schmincke, 1980 ; Hoernle, 1987 ; Garcia Cacho *et al.*, 1987 ; Anguita *et al.*, 1991). The geographical distribution of all these products, as well as their periclinal dips, indicate the possible existence of a stratovolcano situated at what is today the centre of the island (Fig. 1) and which could have reached a height of at least 2,500 m. (Anguita *et al.*, 1991).

The Roque Nublo breccias are the most characteristic deposits of this magmatic cycle. They are very heterogenous (Fig. 2a), with a high percentage of lithic fragments (30-50 % in volume) including examples of each of the Roque Nublo lava flow types, mildly vesiculated pumice (15-20 %), phenocrystals (5-10 %, mainly clinopyroxenes, clinoamphiboles, Fe-Ti oxides and feldspars) and ash matrix (30-40 %). Practically all the glass of the pumice fragments and the ash matrix has been replaced by zeolites, largely chabazite and phillipsite with minor analcime (Brey & Schmincke, 1980). The Roque Nublo breccias are interpreted as the deposit of moderately fluidized and dense pyroclastic flows which were channelled through the radial network of paleovalleys. These materials are thus better classified as non-welded, lithic-rich ignimbrites (Pérez-Torrado, 1990).

Our work is based on the study of melt inclusions trapped in phenocrystals present in the Roque Nublo ignimbrites ; in this study, we try to establish the chemical composition of the melt prior to the explosive eruptions that formed these deposits.

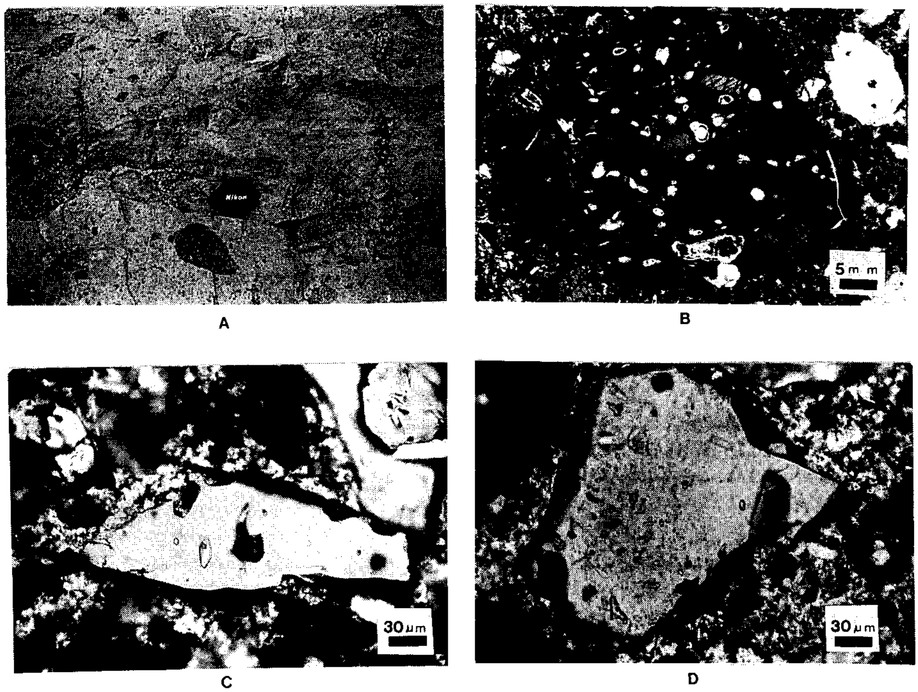

Fig. 2. a) View of the proximal facies of a Roque Nublo ignimbrite. Observe several degassing pipes.
b) Thin section (plane-polarized light). Note that the mildly vesiculated pumice is altered and includes some idiomorphic clinopyroxenes.
c) Example of an isolated melt inclusion in clinopyroxene (plane-polarized light).
d) Melt inclusions occur in clusters as two-phase inclusions : glass and one or several shrinkage bubbles (plane-polarized light).

Chemistry of the Roque Nublo ignimbrites

Rocks as heterogeneous as the Roque Nublo ignimbrites are difficult to sample, particularly for petrological and geochemical studies. An additional problem is the high degree of alteration of the juvenile components (pumice fragments and ash matrix), which are precisely the components which should show the chemical composition of the magma at the time of the explosive eruptions.

Previous investigations have attempted to solve these problems in two different ways. The first approach has been to select the more homogeneous samples and mechanically separate their juvenile components in order to carry out bulk chemical analysis. This method has already been used by Anguita (1972) and Brey & Schmincke (1980). However, thin section point-counting analyses in the above study have proven that samples taken in apparently homogeneous deposits have a submillimetric heterogeneity as great as that seen in the outcrop. The lithic constituents display a complete gradation in size, generally ranging from 20 cm to less than 1 mm, and it is often impossible to distinguish between juvenile crystals and xenocrysts.

The second method has been to analyse the pumice fragments by electron microprobe. However, this method of study, though it may be suitable for classification purposes, has a limited value for the precise characterization of magma compositions because of the high degree of zeolitic alteration. This is clear both from the analyses we have carried out in two different laboratories (University of Paris VI, France, and University of Oviedo, Spain) and also from the results published by Brey & Schmincke (1980) (Table 1).

From the data in Table 1, we can see that the values of SiO_2 and Al_2O_3 are relatively constant

Table 1. Average major element data for the vitric fragments of the Roque Nublo ignimbrites using electron microprobe analyses (Brey 1, 2 : data from Brey & Schmincke, 1980. Paris 1, 2, 3 and Oviedo 1, 2 : analyses done in this work).

	Brey-1	Brey-2	Paris-1	Paris-2	Paris-3	Oviedo-1	Oviedo-2
SiO_2	53.50	51.40	52.81	50.71	55.40	53.75	51.76
TiO_2	2.10	1.10	0.05	0.38	0.76	1.01	0.79
Al_2O_3	20.10	21.00	24.11	23.81	20.40	21.07	23.17
FeO	5.60	3.50	0.00	0.30	3.44	3.22	1.00
MnO	0.00	0.00	0.22	0.00	0.17	0.09	0.00
MgO	1.90	1.00	0.11	0.34	2.22	0.75	0.48
CaO	3.60	2.00	3.56	6.25	2.55	1.29	2.33
Na_2O	5.30	4.10	4.16	5.19	2.03	3.00	4.69
K_2O	4.70	4.60	6.51	2.62	2.58	4.27	4.75
TOTAL	96.80	88.70	91.53	89.60	89.55	88.45	88.97

The operating conditions for the Camebax microprobes at Paris and Oviedo are the same as those used for the melt inclusion analyses (see text for explanation).

and are comparable with phonolitic lavas (Table 2). However, the total sum of oxides is low (< 92 wt %) and the K_2O/Na_2O ratio varies widely (ranging from 0.5 to 1.6) indicating that alteration is always present, masking the initial chemical composition of the pumice fragments. Thus, in the TAS diagram (Le Maitre *et al.*, 1989) of Fig. 4, these pumice fragments plot in the trachyandesite and andesite compositional fields ; Brey & Schmincke (1980) classified the Roque Nublo breccias as phonolitic tephrites and tephrites following the classification of Thornton and Tuttle (1960).

Table 2. Whole-rock analyses of some representatives samples from the Roque Nublo magmatic Cycle of Gran Canaria (data from Perez Torrado, carried out using a Philips 1400 XRF spectrometer at the Ruhr-University, Bochum, Germany).

Samples	BTH-6	BTH-7	LPC-3	LPD-1	BTD-2	BTD-7	TRG-3	TRH-4	BTQ-3	BTÑ-7	BTÑ-8	BTP-3	BTH-2	BTH-3	BTI-4
SiO_2	41.20	42.10	44.10	47.70	46.80	44.80	47.10	44.60	49.62	52.61	56.27	57.40	57.40	50.50	52.20
TiO_2	3.80	3.59	3.94	3.13	3.61	4.32	3.51	4.04	2.72	2.06	1.34	0.75	1.13	1.32	1.26
Al_2O_3	10.93	11.59	12.23	13.24	16.27	15.06	16.37	15.58	18.41	18.79	19.66	20.42	19.13	18.55	18.77
Fe_2O_3	6.66	7.12	6.79	5.47	3.89	5.92	4.28	5.84	4.55	4.46	3.37	1.93	2.44	3.46	2.00
FeO	6.55	5.38	5.99	6.81	5.77	4.93	5.16	5.23	3.23	2.22	1.29	1.71	1.80	1.73	2.92
MnO	0.19	0.19	0.18	0.17	0.19	0.20	0.19	0.19	0.19	0.17	0.17	0.20	0.14	0.18	0.19
MgO	11.65	10.77	7.79	7.15	4.09	4.98	3.95	4.70	2.77	2.22	1.29	0.64	0.95	1.57	1.21
CaO	11.48	11.27	11.42	10.32	8.93	10.60	9.06	9.74	7.99	5.90	3.58	3.00	2.69	4.41	3.62
Na_2O	3.49	3.35	3.02	2.83	3.95	3.76	3.81	3.48	4.97	4.95	6.32	5.80	7.67	9.00	9.11
K_2O	0.86	0.98	0.96	1.06	3.23	2.38	2.60	1.72	2.82	4.04	4.31	5.06	4.83	5.18	5.02
P_2O_5	1.02	1.03	0.88	0.59	0.92	1.18	0.81	1.13	0.72	0.72	0.29	0.14	0.19	0.41	0.28
H_2O	1.39	1.71	1.80	1.56	0.96	1.30	1.75	2.30	2.05	1.60	2.13	1.93	1.48	1.38	1.26
CO_2	0.09	0.07	0.10	0.09	0.02	0.07	0.08	0.02	0.03	0.04	0.04	0.04	0.02	0.15	0.07
TOTAL	99.31	99.15	99.20	100.12	98.63	99.50	98.67	98.57	100.08	99.78	100.04	99.02	99.87	97.84	97.91

BTH-6 and BTH-7 : basanites
LPC-3 and LPD-1 : basalts
BTD-2 and BTD-7 : tephrites
TRG-3 and TRH-4 : trachybasalts
BTQ-3 : basaltic trachyandesite
BTÑ-7 and BTÑ-8 : trachyandesite
BTP-3 : trachyte
BTH-2, BTH-3 and BTI-4 : phonolites

Taking these considerations into account, we adopted a third method of analysis : the study of melt inclusions trapped in juvenile crystals present in the Roque Nublo ignimbrites.

Melt inclusion studies

Characteristics of melt inclusions and host minerals

The samples selected for melt inclusion studies were obtained from several ignimbrite sheets with different stratigraphic and geographic positions and, therefore, belonging to different eruptive pulses (Fig. 1, 3). Doubly-polished wafers of these samples were prepared for microscopic analysis, and the melt inclusions were studied in phenocrysts scattered within the matrix or included in vitric fragments ; inclusions in the phenocrysts of lithic fragments were not considered.

Melt inclusions were observed in clinopyroxene, clinoamphibole and Fe-Ti oxides. Clinopyroxenes were selected because of their abundance in the samples, their optical properties and their content of melt inclusions. The clinopyroxene phenocrysts are nearly idiomorphic in the pumice, whereas in the matrix they are irregular due to the initial fracturing they underwent during eruption and to their latter transport in the pyroclastic flow (Fig. 2b). The chemical compositions of the clinopyroxenes, obtained by electron microprobe, are summarized in Table 3.

The most abundant and representative inclusions in the clinopyroxenes are little or non-evolved melt-inclusions [1]. However, evolved inclusions (optically distinguished by the presence of internal crystals) are also present in small numbers in these minerals. The presence of evolved and low or non-evolved melt inclusions

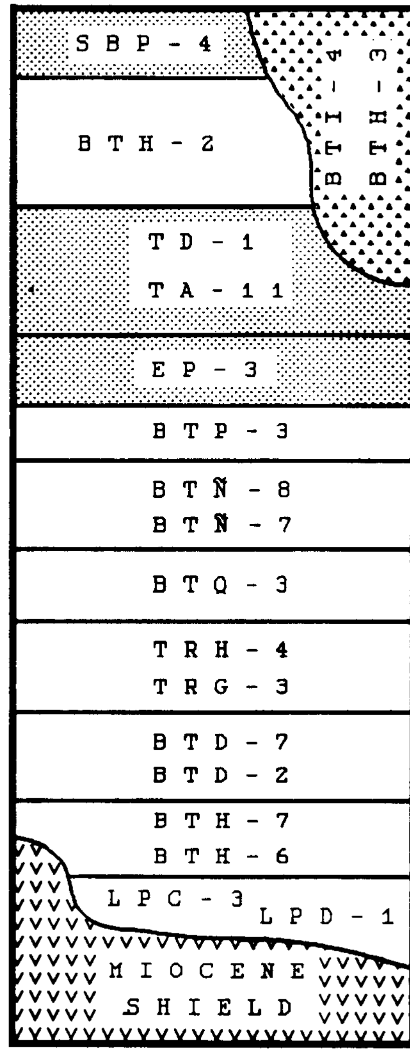

Fig. 3. Generalized stratigraphy of the Roque Nublo magmatic Cycle of Gran Canaria. The sample coding corresponds to that given in Fig. 1 and in Table 2.

[1] The terms of little or non-evolved and evolved melt inclusions were defined by Clocchiatti (1975) and Lin Qi Xia & Clocchiatti (1985).
The little or non-evolved melt inclusions are typical of materials that have crystallized at shallow depths ($P_{total} = P_{fluid} < 4\text{-}5$ kbar) or which have been formed by explosive eruptions. These inclusions are formed when the minerals trap a magmatic liquid in equilibrium with the host mineral. A rapid cooling of the magma preserves the equilibrium between mineral and melt. The chemical composition of these inclusions is fairly close to the parent liquid or, depending on the order of crystallization of the host minerals, is halfway between that of the whole-rock and the mesostasis.
Evolved melt inclusions appear in minerals of rocks which have crystallized at high pressures ($P_{total} = P_{fluid} > 4\text{-}5$ kbar) and also in lava which has cooled very slowly. The chemical composition of these inclusions is different from that of the initial trapped liquid. This is due to the crystallization of host mineral on the walls of the cavity and the formation of crystals derived from the trapped melt.

Table 3. Major element data for the Roque Nublo clinopyroxenes analysed using a Camebax microprobe at the Centre d'Analyse Camparis, Université de Paris VI.

	1	2	3	4	5	6	7
SiO_2	45.71	44.70	46.65	47.33	47.17	46.90	45.54
TiO_2	3.94	4.15	3.23	2.83	2.75	2.61	3.27
Al_2O_3	6.86	7.77	7.28	6.34	5.78	5.71	7.00
Cr_2O_3	0.00	0.00	0.00	0.00	0.16	0.05	0.01
FeO	7.25	9.23	7.57	7.77	7.59	9.18	8.87
MnO	0.34	0.13	0.18	0.32	0.32	0.23	0.11
MgO	11.91	10.49	11.83	11.88	12.14	11.20	10.99
CaO	22.25	21.71	21.68	21.21	21.59	21.84	22.23
Na_2O	0.94	1.30	1.12	1.39	1.12	1.12	1.12
K_2O	0.00	0.00	0.03	0.08	0.05	0.00	0.00
P_2O_5	0.12	0.14	0.12	0.09	0.10	0.11	0.09
TOTAL	99.33	99.62	99.68	99.23	98.77	98.95	99.23

Operating conditions were 15 kV, 40 nA and 10 s. 1 : host clinopyroxene of the TA-11a melt inclusion ; 2 : of the TA-11b, TA-11c and TA-11d melt inclusions ; 3 : TD-1a and TD-1b ; 4 : SBP-4a ; 5 : SBP-4b ; 6 : EP-3a and EP-3b ; 7 : EP-3c (see Table 4 for the melt inclusion nomenclature).

in clinopyroxene crystals confirms juvenile crystals and xenocrystals coexist in these ignimbrites. The evolved melt inclusions probably belong to xenocrystals which have come from fragments of lithic lava.

Under the light microscope, the trapped melt inclusions in clinopyroxene show a heterogeneous distribution, either isolated and/or in discrete clusters, which is indicative of a primary origin (Roedder, 1984) (Fig. 2c, d). Sometimes, they grow close to minerals which have been mechanically trapped in the clinopyroxenes (apatite and Fe-Ti oxides). The inclusions vary greatly in shape, either rounded, elongated or irregular, but the rounded forms are more abundant than the irregular forms. Their size ranges from under 5 to 50 μm, although most of them measure less than 20 μm. Fluid inclusions were not observed in the clinopyroxenes.

At room temperature, most melt inclusions con-

Table 4. Chemical composition of melt inclusions analysed by electron microprobe from 4 selected Roque Nublo ignimbrites (the nomenclature of the 4 samples corresponds to those appearing in Fig. 1).

SAMPLES	EP-3a	EP-3b	EP-3c	TA-11a	TA-11b	TA-11c	TA-11d	TD-1a	TD-1b	SBP-4a	SBP-4b
Nº ANAL.	4	3	5	3	5	4	4	3	4	3	4
SiO_2	57.09(*.13*)	58.17(*.21*)	55.84(*.33*)	53.07(*.32*)	54.40(*.44*)	54.11(*.21*)	54.64(*.40*)	52.49(*.51*)	53.58(*.23*)	58.22(*.19*)	58.11(*.46*)
TiO_2	1.08(*.07*)	1.11(*.01*)	1.01(*.03*)	2.52(*.01*)	1.39(*.02*)	1.55(*.01*)	1.33(*.08*)	1.86(*.05*)	1.95(*.04*)	1.30(*.08*)	0.39(*.01*)
Al_2O_3	21.69(*.23*)	21.62(*.17*)	21.67(*.09*)	22.09(*.61*)	21.95(*.09*)	22.03(*.07*)	22.29(*.01*)	21.31(*.09*)	21.71(*.10*)	22.41(*.01*)	23.98(*.41*)
FeO	1.88(*.18*)	1.65(*.15*)	2.26(*.20*)	4.01(*.05*)	3.31(*.18*)	3.48(*.21*)	3.19(*.10*)	4.32(*.21*)	3.83(*.09*)	2.24(*.04*)	0.48(*.02*)
MnO	0.00	0.00	0.13(*.11*)	0.04(*.04*)	0.05(*.06*)	0.12(*.02*)	0.09(*.07*)	0.13(*.13*)	0.00	0.23(*.04*)	0.00
MgO	0.23(*.02*)	0.24(*.01*)	0.18(*.02*)	1.13(*.02*)	0.43(*.02*)	0.48(*.02*)	0.53(*.03*)	0.66(*.03*)	0.66(*.06*)	0.39(*.01*)	0.01
CaO	0.93(*.04*)	0.97(*.02*)	1.37(*.03*)	1.65(*.02*)	1.55(*.03*)	1.49(*.07*)	1.67(*.13*)	1.63(*.73*)	0.98(*.07*)	0.77(*.04*)	0.21(*.02*)
Na_2O	8.0(*.11*)	7.91(*.10*)	7.78(*.09*)	7.35(*.57*)	8.92(*.20*)	8.64(*.09*)	9.12(*.21*)	8.26(*.02*)	8.31(*.05*)	7.18(*.53*)	8.81(*.49*)
K_2O	6.82(*.04*)	7.19(*.13*)	7.13(*.12*)	6.68(*.03*)	6.57(*.14*)	6.66(*.09*)	6.54(*.02*)	7.66(*.05*)	7.55(*.12*)	6.57(*.11*)	6.48(*.11*)
P_2O_5	0.12(*.04*)	0.13(*.01*)	0.17(*.03*)	0.46(*.01*)	0.32(*.04*)	0.33(*.03*)	0.50(*.20*)	1.06(*.65*)	0.38(*.03*)	0.46(*.02*)	0.11(*.03*)
TOTAL	97.87	98.98	97.55	99.00	98.89	98.89	99.88	99.38	98.96	99.76	98.56

Each reported analysis is the average of several point analyses (the number of point analyses is indicated in the second line as n° anal.). Analyses are only retained if they are internally homogeneous within a given inclusion. The operating conditions are indicated in the text.

tain two phases (glass and one or several shrinkage bubbles), although a small number contain only one phase (glass). The volumetric ratio Vb/Vt (volume of shrinkage bubble/total volume of the inclusion) is less than 5 %. The inclusions have similar volumetric ratios in each clinopyroxene.

Melt inclusion chemistry

Chemical analyses of melt inclusions were carried out using a Camebax microprobe at the Centre d'analyse "Camparis", Université de Paris VI. The operating conditions were 15 kV and 15 nA with a spot defocussed to 8 µm, using different counting times : 10 s for Na ; 15 s for Si, Al, M g, Fe and Mn ; 20 s for Ca, Ti, K. More than 40 melt inclusions analyses were performed on 4 samples of the Roque Nublo ignimbrites ; the major element data are summarized in Table 4. The total sum of oxides is close to 100 %, the sum of alkalis is constant between 13.7 and 15.9 % and the K_2O/Na_2O ratio ranges from 0.7 to 0.9. This range is similar to that shown by the phonolitic lava flows and plugs (0.5 to 0.6). A comparison of the compositions of the melt inclusions with those of the pumice fragments shows that the inclusions were protected from alteration which affected the Roque Nublo ignimbrites and most especially its juvenile fragments.

The major element compositions of the vitric fragments from Table 1, as well as some whole-rock analyses of lava and plugs representing Cycle II from Table 2, and melt inclusion compositions from Table 4, are plotted on the TAS diagram (Le Maitre *et al.*, 1989) in Fig. 4. The melt inclusion data are clustered in the phonolite field, slightly more evolved than the Roque Nublo phonolitic lava and plugs. This may be due to a discrete growth of epitaxic clinopyroxenes in the inclusion walls. In order to evaluate this possible effect, we used mass balance calculations and an oxide versus oxide triangular diagram.

In the mass balance calculations, we demonstrate that it is mathematically possible to obtain one liquid with the same chemical composition as the studied melt inclusions, from another liquid having as same chemical composition of the Roque Nublo phonolite lava flows and plugs, *via* a process of crystal fractionation. For instance, between the BTH-2 phonolite lava flow (the parent magma) and the TD-1a melt inclusion (the daughter magma), we could obtain one from

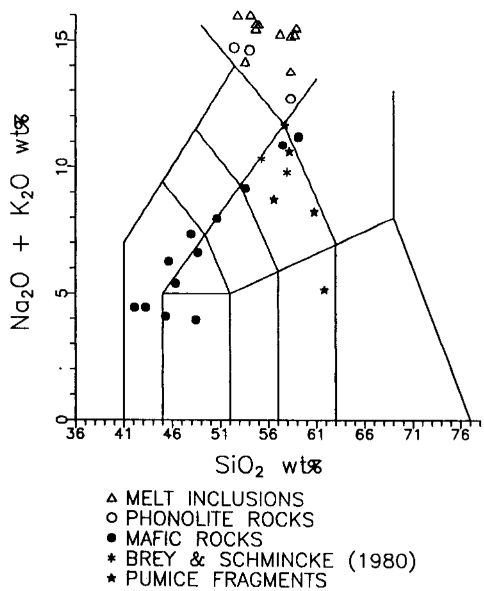

Fig. 4. TAS diagram showing projected the chemical compositions of the vitric fragments from Table 1, some whole-rock analyses of the lava flow and plugs representing Cycle II of Gran Canaria (Table 2) and melt inclusions (Table 3).

the other *via* a process of crystal fractionation. To do so, however, necessitates a large quantity of K-feldspar in order to compensate for the difference in alkali content between the two magmas. The resulting proportions are as follows :

73.3 % K-feldspar
7.7 % Feldspathoid
4.2 % Magnetite
6.5 % Clinopyroxene
7.8 % Daughter liquid

Sum of the squared residuals (r^2) = 0.4.

As regards the melt inclusions, calculations show that it is possible to obtain the TD-1b inclusion from the TD-1a *via* crystallization of 2.4 % clinopyroxene (with $r^2 = 0.4$). However, to obtain TD-1a from EP-3c, we need the intervention of clinopyroxene and also, feldspathoid and Fe-oxide in the following proportions :

1.4 % Clinopyroxene
5.5 % Feldspathoid
2.7 % Magnetite
90.5 % Daughter liquid
$r^2 = 0.7$

Lastly, we can obtain SBP-4b (a melt inclusion belonging to one of the youngest Roque Nublo ignimbrites) from EP-3a (a melt inclusion

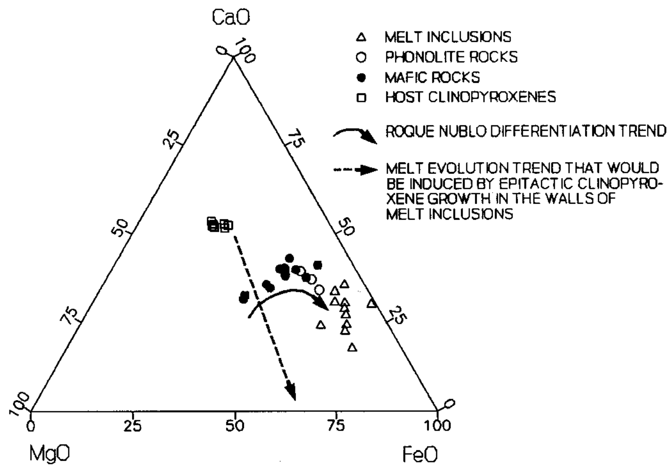

Fig. 5. MgO-CaO-FeO triangular diagram showing a good correlation between the melt inclusions and the rocks from Cycle II. The melt inclusions show a slight variation with respect to the phonolitic rocks ; their compositional trend is a smooth extension of the differenciation trend defined by the chemical composition of the Roque Nublo lava flows.

belonging to one of the first Roque Nublo ignimbrites) with the following values :

2.5 % Clinopyroxene
2 % Magnetite
15 % K-Feldspar
80 % Daughter liquid
$r^2 = 0.69$

Consequently, the evolution of melt inclusions can not only be explained by an effect of epitaxic growth of clinopyroxene (external or internal), but also by the fractionation of feldspathoid, K-feldspar and Fe-oxide. The small amount of fractionation means that the clinopyroxene did not react significantly with the liquid trapped in the inclusion.

The MgO-CaO-FeO triangular diagram in Fig. 5 is used to plot these values in melt inclusions, host clinopyroxenes and the Roque Nublo rocks. In this Figure, we can see how the general evolution of the Roque Nublo magmatic cycle is characterized by an increase of the FeO versus a decrease of the MgO, whilst the CaO increases progressively, diminishing when it reaches phonolitic terms. The melt inclusions are plotted along this marked evolution trend although their contents in CaO and MgO are significantly lower than in the phonolites (see also Tables 2,4). As the clinopyroxene are richer in CaO than in FeO and MgO, an epitaxic growth of the clinopyroxenes in the inclusion walls would basically impoverish the trapped liquids in CaO with respect to the other two oxides. This may have occurred in some of the melt inclusions with lower content in CaO.

We can conclude that the melt inclusions studied are either low or non-evolved and therefore they did not react or only weakly, with the host clinopyroxenes in the time between their entrapment and the explosive eruption of the magma. The chemical composition of the melt inclusions is phonolitic, and therefore we can deduce that the magma which gave rise to the Roque Nublo ignimbrites had a similar composition.

Melt inclusion microthermometry

Melt inclusions were studied with a modified Leitz 1350 heating stage, using the doubly-polished crystal wafers used for microprobe analyses. The oxygen fugacity of the sample compartment is maintained low with an Ar/1 % H_2 gas mixture. The temperature is measured with a Pt - Pt 10 % Rh thermocouple, and corrected for the remaining thermal gradient using calibration with compounds of well-known melting points (Clocchiatti, 1975), in this study the melting point of gold (1063°C). After reaching homogenization (*i.e.* : the temperature at which the shrinkage bubble disappears) the sample is left at this temperature for up to 10 minutes to ensure a well-mixed melt but to avoid dissolving the host or losing volatiles by diffusion. The heating stage experiments yield the minimum temperatures of melt inclusions during the growth of the host crystal (Sobolev & Kostyuk, 1975).

Unfortunately, the number of measurements was small because some of the two-phase inclusions decrepitated during the heating process, others were less than 5 μm in size, which made it impossible to carry out a microthermometry study. Still other inclusions were one-phase. Nevertheless, five homogenization measurements were carried out. They ranged between 1050 ± 15°C and 1150 ± 20°C. The former temperature is more precise because of its proximity to the standard temperature for gold. These homogenization temperature data are similar to those obtained from phonolites by Metrich (1985), Thomas (1990), among others. Using the formula of Thomas (1990) to evaluate the magma crystallization temperature, in combination with geochemical data from phonolite rocks (samples BTH-2, BTH-3 and BTI-4, Table 2), we calculate values between 1023°C and 1067°C.

However, these values seem too high for an evolved magma if we compare them with values traditionally accepted for phonolites. Thus, for instance, Crisp & Spera (1987), using a Fe-Ti oxide geothermometer, obtained temperatures ranging between 835°C and 900°C for phonolitic and trachytic lava flows from Cycle I of Gran Canaria. Possibly, the homogenization temperatures measured are too high because no pressure correction was applied. In their study of the pressure effects on homogenization temperatures of rhyolitic melt inclusion trapped in sanidines, Massare & Clocchiatti (1987) show that these temperatures decrease by approximately 70°C/1 kbar.

Conclusions

The chemical composition of the magma producing the Roque Nublo ignimbrites had not been clearly established until now. This is because whole-rock analyses are unreliable due to the marked heterogeneity of the samples ; furthermore, microprobe analyses of the pumice are hindered by the high degree of alteration. Little or non-evolved melt inclusions trapped in juvenile clinopyroxenes represent a portion of the original magma, and their study in these ignimbrites can help to solve the problem previously outlined. The chemical composition of such inclusions indicates that the composition of the preeruptive Roque Nublo melt was phonolitic. In addition, homogenization measurements (without pressure corrections) carried out in these melt inclusions, yield values ranging between 1050 ± 15 and 1150 ± 20°C.

Acknowledgements : The work was supported by a grant and research project n° 69-1989 of the State University Office of the Canary Island Government. We acknowledge R. Thomas and an anonymous referee for their comments on the manuscript. This study benefited from discussions with H. Ferriz, L. Garcia-Cacho and C. Schirnick.

References

Anguita, F. (1972) : La evolución magmática en el ciclo Roque Nublo (Gran Canaria). *Est. Geol.*, **28**, 377-427.

Anguita, F., Garcia-Cacho, L., Colombo, F., González Camacho, A., Vieira, R. (1991) : Roque Nublo caldera : a new stratocone caldera in Gran Canaria, Canary Islands. *J. Volcanol. Geotherm. Res.*, **47**, 45-63.

Araña, V. & Carracedo, J.C. (1978) : Los volcanes de las Islas Canarias. III Gran Canaria. Rueda éd., Madrid, 175 p.

Brey, G. & Schmincke, H.U. (1980) : Origin and diagenesis of the Roque Nublo breccia, Gran Canaria (Canary Islands) — Petrology of Roque Nublo volcanics, II. *Bull. Volcanol.*, **43**, 15-33.

Clocchiatti, R. (1975) : Les inclusions vitreuses du quartz : données optiques, thermométriques et chimiques. *Mém. Soc. Géol. Fr.*, **122**, 1-96.

Crisp, J.A. & Spera, F.J. (1987) : Pyroclastic flows and lavas of the Mogan and Fataga formations, Tejeda Volcano, Gran Canaria, Canary Islands : mineral chemistry, intensive parameters, and magma chamber evolution. *Contrib. Mineral. Petrol.*, **96**, 503-518.

Garcia Cacho, L., Anguita, F., Araña, V., Barberi, F., Diez-Gil, J.L., Ortiz, R., Sbrana, A. (1987) : Una nueva perspectiva de la Formación Roque Nublo (Gran Canaria). *Bol. Geol. Min. España*, **98-VI**, 859-863.

Hoernle, K. (1987) : General geology and petrology of the Roque Nublo volcanics on Gran Canaria, Canary Islands, Spain. MA Thesis, Univ. Santa Barbara (USA), 191 p.

Le Maitre, R.W. *et al.* (1989) : A classification of igneous rocks and glossary of terms. Blackwell Sci. Publ. ed, Oxford, 193+xi p.

Lin Qi Xia & Clocchiatti, R. (1985) : A new classification of silicate melt inclusions. *Kexue Tonbao*, **30**, 488-492.

Massare, D. & Clocchiatti, R. (1987) : Influence de la pression de confinement sur les températures d'homogénéisation des inclusions fluides et vitreuses. *C.R. Ac. Sci. Paris*, **305**, 1207-1210.

McDougall, I. & Schmincke, H.U. (1976-77) : Geochronology of Gran Canaria, Canary Islands : Age of shield building volcanism and other magmatic phases. *Bull. Volcanol.*, **40**, 57-77.

Metrich, N. (1985) : Mécanismes d'évolution à l'origine des roches potassiques d'Italie centrale et méridionale. Exemples du Mt Somma Vesuve, des Champs Phlégréens et de l'île de Ventotène. Thèse Doctorat, Université d'Orsay. Bull PIRPSEV 110, 1-130.

Perez-Torrado, F.J. (1990) : Roque Nublo non-welded ignimbrite : A type of ignimbrite in Gran Canaria (Canary Islands, Spain). Abstracts book of the International Volcanological Congress, Mainz (FRG).

Roedder, E. (1984) : Fluid Inclusions. *Reviews in Mineralogy*, **12**. Mineralogical Society of America ed., 644 p.

Schmincke, H.U. (1976) : Geology of the Canary Island. *In* "Biogeography and ecology in the Canary Islands", G. Kunkel ed. W. Junk, The Hague, 67-184.

— (1990) : Geological field guide of Gran Canaria. Pluto Press. éd., Witten (FRG), 212 p.

Sobolev, V.S. & Kostyuk, V.P. (1975) : Magmatic crystallization based on a study of melt inclusions. *Nauka Novosibirsk* (in Russian ; translated in part in Fluid Inclusions Res. — Proc. of COFFI, **9**, 182-253).

Thomas, R. (1990) : Abschätzung der bildungstemperatur magmatischer schmelzen. *Z. Geol. Wiss.*, **18**, 5-14.

Thornton, C.P. & Tuttle, O.F. (1960) : Chemistry of igneous rocks. I Differentiation index. *Amer. Jour. Sci.*, **258**, 664-684.

Received 24 June 1991
Accepted 24 April 1992