# Geochronology of Gran Canaria, Canary Islands: Age of Shield Building Volcanism and Other Magmatic Phases

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## ABSTRACT

Forty-six new K-Ar age determinations are presented on whole rock samples and mineral separates from volcanic and subvolcanic rocks of Gran Canaria. The main subaerial shield building basaltic volcanism with estimated volume of about 1000 km$^3$ was confined to the interval about 13.7 m.y. to 13.5 m.y. ago in the middle Miocene. Substantial volume ($\sim$ 100 km$^3$) of silicic volcanics (trachyte and peralkaline rhyolite) were erupted with no detectable time break following the basaltic volcanism, essentially contemporaneous with formation of a large collapse caldera at 13.4 ± 0.3 m.y. ago. Trachytic to phonolitic volcanism continued intermittently in the waning states of activity until about 9 m.y. ago.

Following a long hiatus there was resurgence of volcanism with eruption of about 100 km$^3$ of basanitic to hauyne phonolitic rocks of the Roque Nublo Group between about 4.4 m.y. and 3.4 m.y. ago in the Pliocene. After a hiatus of less than 1.0 m.y., olivine nephelinite magmas were erupted and this activity continued intermittently until relatively recent times, the younger eruptives being mainly basanitic in composition. The volume of volcanic products in this phase probably does not exceed 10 km$^3$. Thus the volume of all the resurgent volcanism comprises less than 10 percent of the subaerially exposed part of Gran Canaria.

The results show that the subaerial main shield building phase of volcanism in Gran Canaria, consisting of mildly alkali to transitional basalts, occurred over a time interval that was less than 0.5 m.y. Magmatic evolution on Gran Canaria appears to be similar to that found on other basaltic volcanoes in oceanic regions. Thus volcanoes in the Hawaiian, Marquesas and Society Islands all were built by basaltic lavas in similar short-lived episodes of volcanism. In some Hawaiian volcanoes, a resurgent phase of volcanism of strongly undersaturated basalts of small volume is recognized following a long hiatus, again similar to that found on Gran Canaria. The relatively large volume of silicic lavas erupted in Gran Canaria immediately following the main basaltic shield building phase is, however, not matched in the Pacific volcanoes mentioned.

## INTRODUCTION

The Canary Islands, situated in the Atlantic Ocean adjacent to the west coast of northern Africa, form an approximately linear volcanic island chain (Fig. 1). Although a rough decrease in age of the volcanism is recognized from east to west along the island chain (ABDEL-MONEM *et al.*, 1971, 1972; SCHMINCKE, 1967, 1973; ANGUITA and HERNAN, 1975), the age progression appears not to be as simple and regular as that found in other volcanic island chains, for example in the Hawaiian, Marquesas and Society Islands in the Pacific Ocean (McDOUGALL, 1964; DUNCAN and McDOUGALL, 1974, 1976). Individual volcanic islands in the Canary Islands have had a long and complex eruptive history, in several cases extending over a period of more than 10 m.y. (ABDEL-MONEM *et al.*, 1972). This is in striking contrast with the Pacific island chains in which the volcanism in individual volcanoes commonly is confined to a time interval of less than one million years (MCDOUGALL, 1964; DUNCAN and MCDOUGALL, 1974, 1976).

The present study was undertaken to investigate the volcanic history of Gran Canaria in more detail, using the K-Ar method, with special emphasis on elucidating the early subaerial history. We shall demonstrate that while Gran Canaria indeed has had a longer and more complex eruptive history than the Pacific volcanoes mentioned, it shows, nevertheless, a number of striking similarities, hitherto not fully recognized. In particular we show that the clearly identifiable main basaltic shield building phase of volcanism on Gran Canaria took place over a period of less than one million years.

## PREVIOUS WORK AND GENERAL GEOLOGY

Gran Canaria is a volcanic island about 45 km in diameter at sea level, rising from ocean depths of more than 2500 m to an altitude of 1950 m. Fuerteventura and Lanzarote to the northeast of Gran Canaria are built adjacent to the continental shelf of Africa whereas Gran Canaria appears to have been constructed on oceanic crust or crust that is transitional between oceanic and continental (DASH and BOSSHARD, 1969; BOSSHARD and MACFARLANE, 1970). The oceanic crust in the vicinity of the Canary Islands is probably of Mesozoic age as it is in the magnetic quiet zone (HEIRTZLER and HAYES, 1967; RONA *et al.*, 1970).

Gran Canaria has a long and complex history and is built of a diversity of volcanic products encompassing a wide range of compositions. Detailed descriptions of the geology of Gran Canaria were given by BOURCART and JEREMINE (1937), HAUSEN (1962), FUSTER *et al.* (1968), and SCHMINCKE (1967, 1968, 1969). Recently SCHMINCKE (1976) reviewed the geological history of the island and introduced new stratigraphic nomenclature which is used throughout this paper (Table 1).

Three major subaerial magmatic phases can be distinguished in Gran Canaria, separated by erosional intervals. The earliest magmatic phase resulted in the construction of a large composite, dominantly basaltic, shield volcano, which encompassed most, if not all, of the present area of the island, and probably extended for several kilometers to the west. Trachyte, rhyolite and trachyphonolite lava flows and welded ash flow deposits covered most of this large volcano. Emission of these silicic volcanics was accompanied by caldera collapse. The caldera so formed was about 15 km in diameter, subsequently to be filled and later intruded by a trachyte cone sheet swarm, syenite bodies and phonolite dikes.

Following a period of erosion, a second cycle of magmatic activity was initiated, the products of which were alkalic silica-undersaturated basanite, ankaramite, tephrite, hauyne phonolite, essexite and spectacular breccia sheets composed of rocks of similar compositions.

A second erosional interval separates this from the third magmatic phase which began with the outpouring of olivine nephelinite flows, followed by the eruption of melilite nephelinite and basanite flows from many local centers. This third phase of volcanism continued until Recent times.

Little was known about the age and duration of volcanism in Gran Canaria prior to the study by ABDEL-MONEM *et al.* (1971), who reported 28 K-Ar ages on rocks from the island as part of a reconnaissance geochronological study of all the Canary Islands. They obtained ages in the range 16 to 9.6 m.y., 3.5 to 3.7 m.y., and several ages in the range 2.0 to 2.8 m.y. for rocks of the first, second and third magmatic phases, respectively. LIETZ and SCHMINCKE (1975) presented K-Ar results on 12 additional samples from the second and third phases. In the present study we have concentrated on the dating of the volcanism of the first phase, although some measurements were also made on rocks from the younger formations.

## METHODS

Samples were collected jointly by both authors. Samples from several of the localities of ABDEL-MONEM *et al.* (1971) were recollected for comparison purposes.

A thin section made from each sample was examined under a petrographic microscope to determine whether the sample would be suitable for age determination. A number of rocks contained alkali feldspar, amphibole or biotite in sufficient amount and a large enough grain size to permit mineral separation which was carried out using heavy

TABLE 1 STRATIGRAPHIC SEQUENCE OF VOLCANIC ROCKS IN GRAN CANARIA (after Schmincke, 1976)

| | | | | |
|---|---|---|---|---|
| POST ROQUE NUBLO VOLCANICS GROUP | La Calderilla Formation: | Basanite pyroclastic cones and lava flows | | MAGMATIC PHASE III (LATE PLIOCENE - QUATERNARY) |
| | | EROSIONAL UNCONFORMITY | | |
| | Unnamed basanitic pyroclastics and lava flows | | | |
| | Los Pechos Formation: | Melilite nephelinite lava flows | | |
| | | EROSIONAL UNCONFORMITY | | |
| | Llanos de La Paz Formation: | Olivine nephelinite lava flows | | |
| | | MAJOR EROSIONAL UNCONFORMITY | | |
| ROQUE NUBLO GROUP | Unnamed younger ankaramites and tephrites at La Fortaleza | | | MAGMATIC PHASE II (PLIOCENE) |
| | Tenteniguada Formation: | Endogeneous domes and lavas of hauynophyre | | |
| | Ayacata Formation: | Lapilli breccia sheets of phonolitic tephrite | | |
| | Presa de Hornos Formation: | Essexite, hauynophyre, basanite and tephrite lavas and intrusives | | |
| | | EROSIONAL UNCONFORMITY | | |
| | Los Listos Formation: | Basanitic and tephritic pyroclastic breccias and lava flows | | |
| | Mesa de Junquillo Formation: | Alkali basalt, ankaramite, tephrite lava flows | | |
| | El Tablero Formation: | Local olivine nephelinite lava flows | | |
| | | MAJOR EROSIONAL UNCONFORMITY | | |
| | Tejeda Formation: | Syenite bodies, trachyte cone sheets and phonolite dikes | Intracaldera | MAGMATIC PHASE I (MIDDLE MIOCENE) |
| | Montaña Horno Formation: | Tuff, breccia, ignimbrite of rhyolitic to phonolitic composition. In part equivalent to Mogan and Fataga Formations. | | |
| | Fataga Formation: | Trachyphonolite to phonolite lavas and ignimbrites | Extracaldera | |
| | Mogan Formation: | Trachyte to rhyolite lavas and ignimbrites | | |
| | | LOCAL EROSIONAL UNCONFORMITIES | | |
| | Hogarzales Formation: | Aphyric to phyric hawaiites and mugearites | | |
| | | EROSIONAL UNCONFORMITY | | |
| | Guigui Formation: | Porphyritic alkali basalts, cut by dikes | | |

liquids and a magnetic separator. The grain purity of the mineral separates normally was better than 98 percent. Most of the basaltic rocks were too fine grained for mineral separation and therefore were measured as whole rock samples. Only those samples were accepted for dating that were well crystallized and virtually free of alteration. In several cases, however, rocks containing some glass or poorly crystallized mesostasis were used for whole rock dating. Petrographic descriptions of the samples and locality details are given in the Appendix.

The whole rock samples were crushed to a size of 0.5 to 1.0 mm, an aliquot was taken and crushed to less than 0.1 mm and reserved for potassium analysis by flame photometry. In the case of mineral separates the potassium and argon were measured on aliquots which were not crushed further. Argon was determined by isotope dilution with $^{38}$Ar as the tracer prepared from a gas pipette system. Normally 10 to 15 g of the coarser crushing of the whole rock, and up to 2 g of mineral separate, was used for argon extraction. The whole rock samples were not baked in the argon extraction line above about 120°C prior to the extraction of argon to minimize the possibility of isotopic fractionation of a loosely air argon component of the type described by BAKSI (1974). Following fusion of the sample in the extraction line and purification of the gases, the isotopic composition of the argon was measured in a substantially modified AEI MS10 mass spectrometer fitted with a 4.2 kilogauss permanent magnet. An automatic switching device was used to alter the accelerating voltage to focus the ion beam for individual masses on the Faraday cup collector, and base lines also were measured between the peaks. The ion beams were detected with a Cary 401 electrometer, fed to a voltage to frequency convertor and a counter-timer and then directly on-line into a Hewlett-Packard 2116B computer in which all data reduction was done. Estimates of precision, give in the tables of results, are derived directly from the precision of the physical measurements (MCDOUGALL *et al.*, 1969), and the uncertainty quoted is arrived at by quadratically combining the precision from the potassium, tracer calibration and isotope ratio measurements. Constants used in the calculation of ages were: $\lambda_e = 0.585 \times 10^{-10} y^{-1}$; $\lambda_\beta = 4.72 \times 10^{-10} y^{-1}$; $^{40}K/K = 1.19 \times 10^{-4}$ mol/mol.

The philosophy adopted in this study has been to measure K-Ar ages on a relatively large number of samples in known stratigraphic relationship to one another. Such an approach allows the basic assumptions that are made in calculating a K-Ar age from the analytical data to be evaluated through consistency or otherwise of the results.

## RESULTS

The results of the K-Ar dating are discussed below in stratigraphic order from oldest to youngest, following the stratigraphic framework shown in Table 1. The physical time scale used in this work follows that suggested by BERGGREN and VAN COUVERING (1974) who place the Oligocene-Miocene boundary at about 23 m.y., the Miocene-Pliocene boundary at 5.0 m.y., and the Pliocene-Pleistocene boundary at about 1.7 m.y. The K-Ar results are given in Tables 2 to 5.

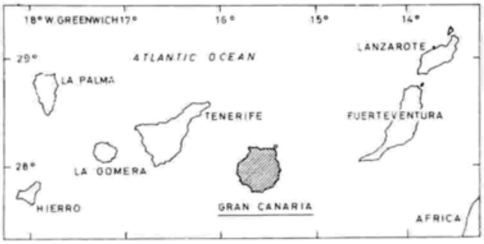

FIG. 1 - Map of the Canary Islands and part of Africa.

### *Guigui and Hogarzales Formations*

The oldest exposed rocks on Gran Canaria, representing the main shield building phase of volcanism, are nearly flat-lying thin basaltic lavas about 1000 m thick which occur mainly adjacent to the west coast (Fig. 2). Two formations are distinguished by SCHMINCKE (1976), the oldest, the Guigui Formation, consisting of thin basaltic flows of mildly alkaline to transitional composition, locally cut by dikes. These basalts range from

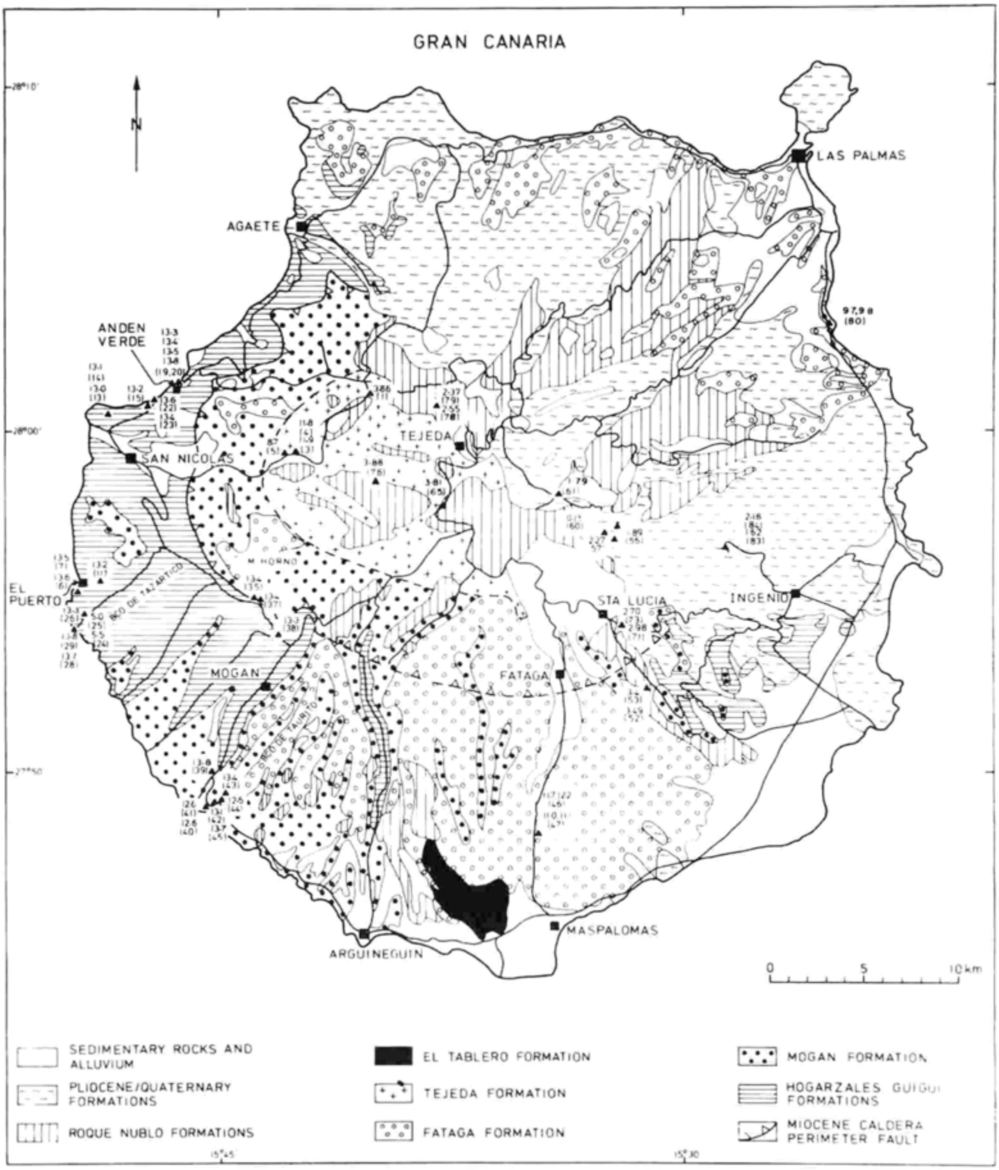

FIG. 2 - Simplified geological map of Gran Canaria showing sample localities and K-Ar ages. Geology simplified after FUSTER *et al.* (1968) and SCHMINCKE (1967, 1968). Map modified from SCHMINCKE (1976). Numbers are ages in millions of years; numbers in parentheses are sample numbers.

aphyric to porphyritic lavas containing abundant olivine or olivine and clinopyroxene and rarer plagioclase phenocrysts. This formation is well exposed on the west coast between El Puerto and Barranco de Tazartico (Fig. 2), and five samples have been dated from this area (Table 2). Two samples (GC28, GC29), collected at sea level at the mouth of Barranco de Tazartico give concordant ages of 13.8 m.y., and are thought to be the stratigraphically lowest samples collected. Both rocks are fresh, holocrystalline, olivine-bearing basalts showing only minor alteration, and this fact together with the concordancy of the results gives us confidence that the measured ages approximate closely the age of crystallization of the lavas. Sample GC6 is from a flow with olivine phenocrysts near El Puerto and yields a slightly younger calculated age of 13.6 ± 0.3 m.y. and is cut by a 1 m wide dike, a sample (GC7) from which gives an age of 13.5 ± 0.3 m.y. These ages are not significantly different from those found for the samples from Barranco de Tazartico, and the best estimate of age of the Guigui Formation is given by the average of all four results, 13.65 m.y., with a standard deviation of 0.14 m.y. The average age of 13.3 m.y. for the basalt sample GC26 (Table 2) from the Guigui Formation would appear to be slightly too young on this basis, presumably because of some loss of radiogenic argon. This basalt contains a few percent of poorly crystallized mesostasis and sporadic clay filled vesicles and this material may not have retained its radiogenic argon quantitatively. Nevertheless, including the result on GC26, the overall mean age for the Guigui Formation is 13.59 ± 0.20 m.y. When plotted on an isochron diagram (McDougall *et al.*, 1969), in which $^{40}Ar/^{36}Ar$ is the ordinate and $^{40}K/^{36}Ar$ is the abscissa, the Guigui basalt data give a regression line with a slope equivalent to an age of 13.50 ± 0.16 m.y. (Fig. 3); here the quoted uncertainty is one standard deviation. Collectively, the results strongly suggest that the basalts of the Guigui Formation were erupted over a rather short interval of time, probably less than 0.3 m.y., at about 13.7 m.y. ago.

In the vicinity of El Puerto on the west coast the lavas of the Guigui Formation have been eroded and a younger series of volcanics, the Hogarzales Formation, overlie this erosional unconformity (see

TABLE 2 POTASSIUM-ARGON AGES ON WHOLE ROCK SAMPLES FROM SHIELD BUILDING BASALTS OF GUIGUI AND HOGARZALES FORMATIONS, GRAN CANARIA

| Field No. | Lab. No. | Material | K (wt. %) | Rad. $^{40}Ar$ ($10^{-11}$ mol/g) | 100 Rad. $^{40}Ar$ / Total $^{40}Ar$ | Calculated Age (m.y.) ± 2 s.d. | Locality | |
|---|---|---|---|---|---|---|---|---|
| Hogarzales Formation | | | | | | | | |
| GC22 | 74-187 | Hawaiite | 1.156,1.156 | 2.798<br>2.821 | 88.2<br>80.1 | 13.5±0.3<br>13.7±0.3 | Altitude 420 m | San Nicolas to Agaete road, about 2 km SW of Montaña Blanca between 60 and 61 km posts |
| GC23 | 74-188 | Hawaiite | 0.947,0.949 | 2.273<br>2.252 | 88.0<br>82.7 | 13.4±0.3<br>13.3±0.3 | Altitude 410 m | |
| GC15 | 74-180 | Hawaiite | 1.447,1.456 | 3.424 | 79.7 | 13.2±0.3 | Altitude 350 m | |
| GC13 | 74-178 | Hawaiite | 1.184,1.184 | 2.756 | 75.8 | 13.0±0.3 | Altitude ∿100m | W coast, ∿0.5 km N of Puerto de la Aldea |
| GC14 | 74-179 | Hawaiite | 1.321,1.312 | 3.078 | 74.4 | 13.1±0.3 | Altitude ∿80m | |
| GC11 | 74-176 | Hawaiite | 0.905,0.909 | 2.141 | 77.2 | 13.2±0.3 | 0.7 km E of W coast at El Puerto | |
| Guigui Formation | | | | | | | | |
| GC7 | 74-172 | Basalt | 0.924,0.932 | 2.235 | 81.0 | 13.5±0.3 | 1 m wide dike | 0.5 km SE of El Puerto, W Coast |
| GC6 | 74-171 | Basalt | 0.642,0.635 | 1.553 | 74.4 | 13.6±0.3 | flow cut by GC7 | |
| GC26 | 74-192 | Basalt | 0.823,0.817 | 1.924<br>1.981 | 58.2<br>51.0 | 13.1±0.3<br>13.5±0.3 | 0.9 km from W coast, Barranco de Tazartico | |
| GC28 | 74-194 | Basalt | 0.813,0.814 | 2.024<br>1.973 | 64.1<br>51.0 | 13.9±0.3<br>13.6±0.3 | W coast at mouth of Barranco de Tazartico | |
| GC29 | 74-195 | Basalt | 1.117,1.121 | 2.765<br>2.768 | 56.5<br>51.6 | 13.8±0.3<br>13.8±0.3 | | |

fig. 13 in SCHMINCKE, 1968). The Hogarzales lavas are gently dipping like the underlying lavas and consist of thick hawaiite to mugearite (trachybasalt) flows and locally, particularly to the north of San Nicolas, olivine phyric and plagioclase phyric basalts are common. At Anden Verde, 5 km north of San Nicolas, adjacent to the northwest coast, this formation is overlain conformably by a composite rhyolite-mugearite flow and silicic volcanics of the Mogan Formation.

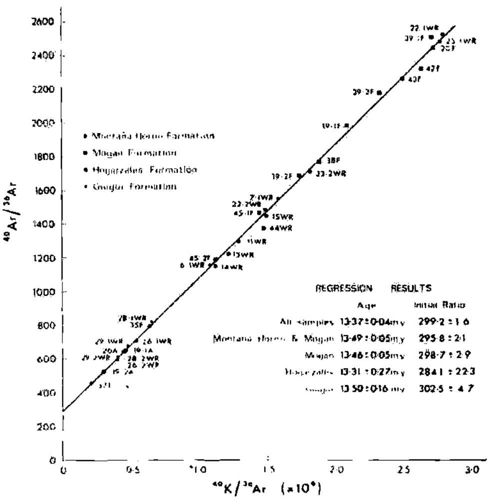

FIG. 3 - Potassium-argon isochron diagram showing the results from the shield building basalts and the related silicic volcanics. Samples identified by the field number. Replicate analyses are identified and A refers to amphibole, F to alkali feldspar and WR to whole rock. Regression results, calculated by the method of YORK (1969), are shown with errors quoted at one standard deviation. Note that in general at the level of two standard deviations the intercept value on the $^{40}Ar/^{36}Ar$ axis does not differ significantly from the atmospheric argon value of 295.5 Line drawn on diagram is the least squares regression through all the data points.

Six samples were dated from the Hogarzales Formation (Table 2). Sample GC11 is a platy, fine grained, somewhat oxidized hawaiite adjacent to the erosional unconformity with the Guigui Formation, 0.7 km east of the coast at El Puerto, and yields a K-Ar age 13.2 ± 0.3 m.y. This suggests that the erosional interval between the two formations is short, probably no more than 0.5 m.y. The remaining five ages, ranging from 13.6 to 13.1 m.y., on Hogarzales Formation lavas were determined on samples from the well-exposed sequence adjacent to the coast between San Nicolas and Anden Verde. The mean of all six ages and standard deviation is 13.24 ± 0.21 m.y., only 0.4 m.y. younger than the mean age for the Guigui Formation. However, the stratigraphically highest lava dated (GC22), about 100 m below the base of the overlying Mogan Formation, yields a reproducible age of 13.6 m.y., which is concordant with the age of the Guigui Formation samples. This age is significantly older than those determined on the four samples lower down in the same sequence, suggesting that some loss of radiogenic argon may have occurred from these four samples. In this connection it may be noted that GC13, 14 and 15 in particular are finely vesicular and contain small amounts of yellow clay and have fine grained to cryptocrystalline groundmasses, whereas GC22 is a dense, very fine grained but well crystallized rock and is therefore likely to retain radiogenic argon better. On the isochron diagram, data from the Hogarzales Formation are well correlated and yield an isochron age of 13.3 ± 0.3 m.y. (Fig. 3), not resolvably younger than the age of the underlying Guigui Formation.

The K-Ar ages on lavas from the Guigui and Hogarzales Formations collectively indicate that the shield building, dominantly basaltic rocks of Gran Canaria were erupted over an interval of time of substantially less than 1 m.y. and probably less than 0.5 m.y.

Our generally concordant results contrast with those of ABDEL-MONEM *et al.* (1971) who reported K-Ar ages ranging from 10.2 to 16.1 m.y. on five basaltic rock samples from Basaltic Series I of FUSTER *et al.* (1968). From the localities given in their paper the samples dated by **Abdel-Monem** *et al.* appear to have been collected from the Hogarzales Formation. The two youngest ages of 10.2 ± 0.7 m.y. (GCU10, GCU11) found by **Abdel-Monem** *et al.* (1971) may reflect considerable argon loss. The older apparent ages, which range from 15.0 to 16.1 m.y., are more difficult to understand. The only plausible explanation is that there was laboratory-induced fractionation of the atmospheric argon component in the samples during bakeout in the vacuum system prior to argon extraction. Such a situation could have led to improper correction for atmospheric $^{40}$Ar and causing the calculated ages to be too great (cf. **Baksi**, 1974; **McDougall** *et al.*, 1976). Such effects are particularly noticeable in rocks that are altered or weathered and contain clay minerals.

### *Mogan Formation*

The shield building basaltic lavas of the Guigui and Hogarzales Formations are overlain, usually conformably, by up to 500 m of silica-oversaturated to saturated trachytic to rhyolitic lavas and ignimbrites of the Mogan Formation. The sequence, which becomes increasingly peralkaline upwards, is shown diagrammatically in Fig. 4.

The basal unit of the Mogan Formation is a distinctive soda-rich rhyolitic ignimbrite (P1) that grades upward into a mugearitic lava, and therefore is best described as a composite flow (**Schmincke**, 1969). This unit is very widespread as it crops out over at least 200 km². Alkali feldspar (anorthoclase) and amphibole (edenite) phenocrysts, which are common in the lower part of the cooling unit, were separated from two samples (GC19, GC20) collected at a locality on the road adjacent to the northwest coast at Anden Verde, near Montaña Blanca. Here the composite flow lies conformably on the basaltic lavas of the Hogarzales Formation. The K-Ar ages (Table 3) are virtually concordant at 13.5 ± 0.2 (s.d.) m.y., and experimentally indistinguishable from the mean ages for the underlying shield building basalts. Thus no significant hiatus in the volcanism is indicated between the Hogarzales Formation and the Mogan Formation; this is consistent with the geological evidence of conformable relationships and no erosional break between the

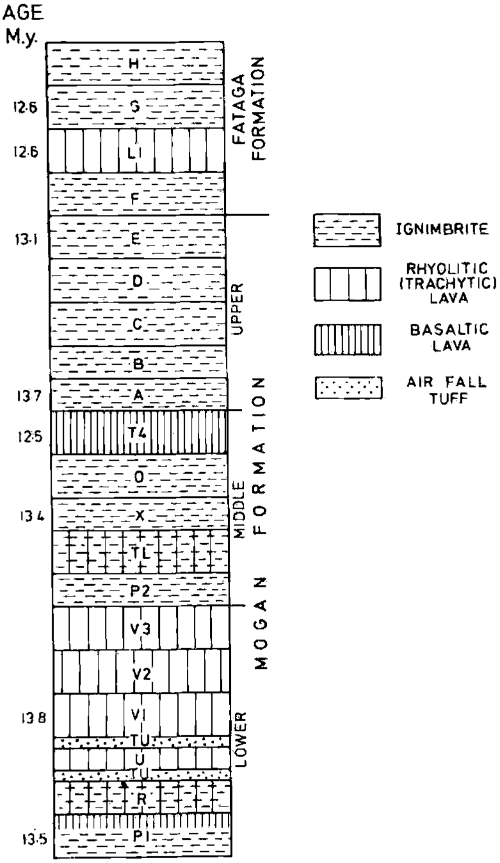

Fig. 4 - Diagram illustrating the stratigraphy of the Mogan Formation and the lower part of the Fataga Formation (after **Schmincke**, 1969, 1976). Measured ages are indicated; the error of each age is 0.3 m.y. at the level of two standard deviations.

basaltic rocks and the composite flow (SCHMINCKE, 1967). ABDEL-MONEM *et al.* (1971) obtained an age of 13.1 ± 0.5 m.y. for feldspar separated from the same composite flow at the same locality, in good agreement with our results. However, they also reported a K-Ar age of 15.0 ± 0.4 m.y. on a whole rock sample of sodarhyolite (GCU15) overlying the composite flow. The inconsistency of the ages was noted by ABDEL-MONEM *et al.* (1971), and it is now clear that the older age is erroneous.

Age measurements also were made on alkali feldspar phenocrysts separated from four other rhyolitic lavas or ignimbrites of the Mogan Formation from near the southwest coast of Gran Canaria in the vicinity of Barranco de Taurito (Table 3; Figs. 2 and 4). These ages range from 13.8 ± 0.3 m.y. (GC39) to 13.1 ± 0.3 m.y. (GC42) the latter samples being from ignimbrite E, the stratigraphically highest member in the Mogan Formation (SCHMINCKE, 1976). ABDEL-MONEM *et al.* (1971) also obtained an age of 13.1 ± 0.3 m.y. on a sample (GC90) from ignimbrite E. Alkali feldspar (GC38) from a rhyolite dike cutting the older basalts and correlated with the Mogan Formation volcanics gives an age of 13.3 ± 0.3 m.y. A whole rock sample (GC44) from the trachybasalt lava T4 in the Mogan Formation yields a younger age of 12.5 m.y., inconsistent with the other results; we conclude that this sample has lost some radiogenic argon by diffusion, although it is well crystallized and relatively fresh.

The spread in apparent ages from 13.8 to 13.1 m.y. for the feldspars from the Mogan Formation is greater than expected from experimental error alone, suggesting that a difference in age has been detected, or that excess argon occurs in some samples, or that there has been open system behaviour. It is difficult to distinguish unambiguously between these possibilities so that it is probably best to accept all the ages on mineral separates at face value. Giving unit weight to the results from each sample, we obtain a mean age of 13.48 ± 0.25 (s.d.) m.y. for the Mogan Formation, virtually the same as the age obtained using the isochron approach (Fig. 3). As this age is statistically indistinguishable from the age of the basaltic shield building volcanism we conclude that the change from basaltic to rhyolitic volcanism occurred with no significant or detectable time break.

TABLE 3 POTASSIUM-ARGON AGES ON SAMPLES FROM MONTANA HORNO AND MOGAN FORMATIONS, GRAN CANARIA

| Field No. | Lab. No. | Material | K (wt.%) | Rad. $^{40}$Ar ($10^{-11}$ mol/g) | $\frac{100\ \text{Rad.}\ ^{40}\text{Ar}}{\text{Total}\ ^{40}\text{Ar}}$ | Calculated Age (m.y.)±2 s.d. | Locality |
|---|---|---|---|---|---|---|---|
| Intracaldera tuffs and rhyolites (Montaña Horno Formation) | | | | | | | |
| GC37 | 74-203 | Alkali feldspar | 4.411,4.387 | 10.50 | 35.0 | 13.4±0.4 | Rhyolite, caldera margin, Montaña Horno |
| GC35 | 74-201 | Alkali feldspar | 4.501,4.523 | 10.80 | 62.7 | 13.4±0.3 | Basal tuff, caldera wall, Montana Horno |
| Extracaldera ignimbrites and flows (Mogan Formation) | | | | | | | |
| GC42 | 74-208 | Alkali feldspar | 3.985,3.991 | 9.30 | 87.2 | 13.1±0.3 | Ignimbrite E<br>Coastal road, 0.5 - 1.5 km E to SE of Puerto de Mogan, SW coast near Barranco de Taurito |
| GC45 | 74-211 | Alkali feldspar | 2.893,2.911 | 7.17<br>7.06 | 79.9<br>75.2 | 13.8±0.3<br>13.6±0.3 | Ignimbrite A |
| GC44 | 74-210 | Trachybasalt | 1.069,1.070 | 2.39 | 78.6 | 12.5±0.3 | Trachybasalt T4 |
| GC43 | 74-209 | Alkali feldspar | 3.995,3.987 | 9.54 | 86.9 | 13.4±0.3 | Ignimbrite X |
| GC39 | 74-205 | Alkali feldspar | 1.579,1.574 | 3.90<br>3.86 | 88.2<br>86.4 | 13.9±0.3<br>13.7±0.3 | Rhyolite V1, 1.5 km NNE of Puerto de Mogan |
| GC38 | 74-204 | Alkali feldspar | 1.561,1.552 | 3.71 | 83.3 | 13.3±0.3 | Rhyolite dike, 3 km NNW of Mogan |
| GC20 | 74-185 | Alkali feldspar | 2.088,2.086 | 4.99 | 87.8 | 13.4±0.3 | Composite rhyolite-basalt flow P1, Montana Blanca on San Nicolas - Agaete road, adjacent to NW coast, altitude 530 m. |
| | | Amphibole | 0.518,0.519 | 1.248 | 54.0 | 13.5±0.3 | |
| GC19 | 74-184 | Alkali feldspar | 2.042,2.034 | 5.01<br>4.98 | 85.1<br>82.5 | 13.8± 0.3<br>13.7± 0.3 | |
| | | Amphibole | 0.515,0.509 | 1.203<br>1.226 | 54.3<br>43.7 | 13.2± 0.3<br>13.4± 0.4 | |

### *Montaña Horno Formation*

Major collapse of the basaltic shield volcano resulted in the formation of a caldera about 15 km in diameter and at least 1000 m deep (SCHMINCKE, 1967, 1968). The trace of the caldera margin is indicated on the map (Fig. 2). At least some, if not most of the collapse occurred after eruption of the composite flow P1, which is everywhere cut by the caldera fault and which is not found exposed within the caldera. The collapse structure was filled by a sequence of rhyolitic, trachytic and trachyphonolitic tuffs, flows, ignimbrites and intrusions, which together comprise the Montaña Horno Formation.

Samples were collected from the southern flanks of Montaña Horno at the caldera margin, 5 km north of Mogan in the southwestern part of the island. Sample GC35 is a green unwelded pumice flow deposited on the inside of the caldera and only separated from the shield building basalts by the caldera margin fault. Sample GC37 is a rhyolitic intrusion about 100 m from the caldera margin and within the caldera. Alkali feldspar separated from these two samples yield identical K-Ar ages of 13.4 m.y. (Table 3). Thus we have an age of 13.5 ± 0.2 m.y. for composite flow P1, the eruption of which preceded caldera collapse, and ages of 13.4 ± 0.3 m.y. for two samples from the Montaña Horno Formation which were erupted subsequent to caldera formation. These ages are indistinguishable from one another and within the errors cannot be distinguished from the ages on the shield building basalts or those measured on the Mogan Formation. We conclude that all these events took place over an interval of time not resolvable by the K-Ar dating method, probably in less than 0.5 m.y.

### *Fataga Formation*

The slightly silica undersaturated trachytic to phonolitic ignimbrites and lavas of the Fataga Formation generally lie conformably on the silica oversaturated volcanics of the Mogan Formation; locally a thin conglomeratic bed occurs between the top of the Mogan (rhyolitic ignimbrite E, Fig. 4) and the base of the Fataga (trachytic ignimbrite F) Formations.

Five K-Ar ages were measured on samples from the Fataga Formation (Table 4). Alkali feldspar separated from samples from two of the basal cooling units (ignimbrite G and lava flow L1) overlying the Mogan Formation in Barranco de Taurito give identical ages of 12.6 ± 0.3 m.y. Although the Mogan and Fataga Formations are conformable and locally only separated by a thin bed of conglomerate, the K-Ar ages suggest that there may have been a hiatus between them in the order of 0.5 m.y. Between Maspalomas and Fataga, in the southern part of Gran Canaria, two samples (GC46, GC47) from a phonolite unit from the upper part of the formation yielded K-Ar ages on alkali feldspar averaging 11.9 ± 0.3 m.y. and 11.1 ± 0.3 m.y. respectively. The difference between the ages is outside that expected from experimental error alone; we do not have a satisfactory explanation for this discrepancy. ABDEL-MONEM *et al.* (1971) dated a whole rock sample from the same locality at 10.3 ± 0.1 m.y., which is a significantly younger apparent age than we obtained on separated alkali feldspar phenocrysts. This may be because of argon loss from the sample that ABDEL-MONEM *et al.* dated, as in the samples that we collected the groundmass feldspar and nepheline showed considerable deuteric alteration.

On the northeast coast of Gran Canaria, about 6.5 km south of Las Palmas, a 30 m thick phonolite lava crops out. A sample (GC80) from this flow yielded concordant ages of 9.7 and 9.8 m.y. on whole rock and separated alkali feldspar phenocrysts respectively; these are in such good agreement that there can be little doubt that this is the age of eruption of this lava which is correlated with the Fataga Formation. ABDEL-MONEM *et al.* (1971) measured K-Ar ages on two whole rock samples from this same unit and obtained ages of 9.6 ± 0.1 m.y. and 9.8 ± 0.1

TABLE 4 POTASSIUM-ARGON AGES ON SAMPLES FROM FATAGA AND TEJEDA FORMATIONS, GRAN CANARIA

| Field No. | Lab. No. | Material | K (wt.%) | Rad. $^{40}Ar$ ($10^{-11}$ mol/g) | $\frac{100\ \text{Rad.}\ ^{40}Ar}{\text{Total}\ ^{40}Ar}$ | Calculated Age (m.y.) ± 2 s.d. | Locality |
|---|---|---|---|---|---|---|---|
| Extracaldera phonolites (Fataga Formation) | | | | | | | |
| GC80 | 74-93 | Phonolite<br>Alkali feldspar | 4.553,4.546<br>5.057,5.038 | 7.89<br>8.84 | 93.6<br>92.0 | 9.7 ± 0.2<br>9.8 ± 0.2 | 30 m thick flow, Punta del Palo,<br>E coast, 6.5 km S of Las Palmas toward Gando |
| GC47 | 74-213 | Alkali feldspar | 5.474,5.455 | 10.80<br>10.76 | 39.4<br>39.9 | 11.1± 0.3<br>11.0± 0.3 | Phonolite flow(s), 5 km N of Maspalomas on road to Fataga |
| GC46 | 74-212 | Alkali feldspar | 5.363,5.297 | 11.59<br>11.17 | 65.8<br>43.8 | 12.2± 0.3<br>11.7± 0.4 | |
| GC41 | 74-207 | Alkali feldspar | 4.640,4.557 | 10.20 | 85.2 | 12.6± 0.3 | Trachyphonolite lava L1<br>SW coast near Barranco de Taurito |
| GC40 | 74-206 | Alkali feldspar | 3.474,3.501 | 7.82 | 94.5 | 12.6± 0.3 | Ignimbrite 6 |
| Intracaldera syenites and phonolites (Tejeda Formation) | | | | | | | |
| GC5 | 74-170 | Phonolite | 4.080,4.068 | 6.33 | 77.6 | 8.7± 0.1 | Dike, 11 m wide, 200 m NW of Paralillo dam |
| GC3 | 74-168 | Biotite | 7.398,7.398 | 15.72 | 54.9 | 11.9± 0.3 | Syenite intrusives, just below Paralillo dam, road Artenara to San Nicolas |
| GC4 | 74-169 | Biotite | 7.410,7.338 | 15.55 | 66.3 | 11.8± 0.3 | |

m.y., in excellent agreement with our results.

Our data indicate that the phonolite flows included within the Fataga Formation were erupted over a rather long interval of time, in the order of 3 m.y., following the main shield-building basaltic and trachytic-rhyolitic phase.

## *Tejeda Formation*

Within the deeper parts of the present erosion caldera of Gran Canaria, to the west and south of Tejeda, are exposed several syenite intrusives, numerous younger trachyte dikes (cone sheets) and some still younger phonolite dikes, all of which are considered by Schmincke (1967) to be younger than the basaltic shield-building phase, contrasting with some earlier views (*e.g.*, Hausen, 1962) that they preceded the construction of the main basaltic volcano. Prior to the present study no age determinations were available for this formation.

Biotite from two samples (GC3, GC4) of relatively coarse grained intrusive syenite near Paralillo dam yielded concordant ages of 11.9 and 11.8 m.y. (Table 4). The ages are in the range of those found for the Fataga Formation, supporting the interpretation of Schmincke (1967) that the two formations are coeval. A phonolite dike intruding syenite and the trachytic cone sheet swarm near Paralillo dam gives an age on a whole rock sample (GC5) of 8.7 m.y., somewhat younger than the youngest age found for the phonolites of the Fataga Formation.

## *El Tablero Formation*

Most authors have recognized a major erosional gap between the main shield building phase of volcanism and the younger more alkalic formations comprising the Roque Nublo Group. However, in the southern part of the island a few local occurrences of obviously valley filling flows were recognised (Hausen, 1962; Schmincke, 1968). A nephelinite flow of this kind at El Tablero gave a K-Ar age of 4.86 ± 0.15 m.y. (Lietz and Schmincke, 1975). In the present study we have sampled and dated a similar nephelinite lava that clearly fills a deep valley cut in the Guigui Formation basalts in Barranco de Tazartico near the west coast of Gran Canaria (Schmincke, 1968, fig. 26). Two whole rock samples (GC24, GC25) from this flow yield K-Ar ages of 5.5 and 5.0 m.y. respectively, quite similar in age to that found for the El Tablero Formation, with which we tentatively correlate it. The difference in measured age between the two samples is larger than can be accounted for by experimental error. Both the samples contain no recognizable plagioclase but abundant slightly altered and turbid nepheline or glass and some analcite. It is possible that the nepheline has leaked some radiogenic argon, so that both ages must be regarded as minima.

### *Roque Nublo Group*

The second major volcanic phase in the geological history of Gran Canaria consists of a series of lavas ranging from basanites and ankaramites to highly alkalic phonolites, essexite and hauynophyre intrusives and a sequence of strongly zeolitized breccia sheets, all included within the Roque Nublo Group. ABDEL-MONEM *et al.* (1971) reported K-Ar ages of 3.75 and 3.5 m.y. on two samples from the Roque Nublo Group, and LIETZ and SCHMINCKE (1975) presented results on eight additional samples which gave ages between 4.40 and 3.68 m.y. LIETZ and SCHMINCKE (1975) proposed that Roque Nublo volcanism extended from about 4.4 to 3.7 m.y. ago and suggested that the 3.5 m.y. age given by ABDEL-MONEM *et al.* (1971) is probably too young owing to argon loss.

In this study we have measured ages on five more samples from the Roque Nublo Group. Three of these samples (GC1, 65, 76) were collected from different localities near the center of the island within 7 km of Tejeda (Fig. 2). Ages on these samples are concordant and lie between 3.81 and 3.88 m.y. (Table 5). Both GC65 and GC76 are from lava flows near the base of the local Roque Nublo succession but from rather high in the total section. Sample GC1 is from a hauyne phonolite intrusion and its measured age of 3.86 ± 0.06 m.y. agrees well with ages of 3.68 ± 0.18 m.y. and 3.75 ± 0.12 m.y. reported by LIETZ and SCHMINCKE (1975) and ABDEL-MONEM *et al.* (1971) for two other hauyne phonolite intrusions. Stratigraphic evidence suggests that Roque Nublo volcanism culminated with the emplacement of these hauyne phonolites.

The remaining two Roque Nublo samples (GC52,53) dated in this study are from a succession of lavas at La Fortaleza, southeast of Santa Lucia. The measured ages are respectively 3.49 and 3.40 m.y. (Table 5), in satisfactory agreement with an age of 3.50 m.y. obtained by ABDEL-MONEM *et al.* (1971) on sample GCU29A from the same sequence. Further to the southeast toward the coast in the same barranco LIETZ and SCHMINCKE (1975) reported the age of 3.96 ± 0.10 m.y. on sample P15, an alkali basalt of the Roque Nublo Formation. Nevertheless the concordant ages from the La Fortaleza lavas suggest that Roque Nublo volcanism continued in this area until about 3.45 m.y. ago.

### *Post Roque Nublo Volcanism*

Much of the northeastern part of Gran Canaria is covered by a veneer of relatively young strongly alkaline and silica-undersaturated lavas and pyroclastics ranging from olivine nephelinite, and melilite nephelinite to basanite in composition (Fig. 2). These volcanics together comprise the last major phase of volcanism on Gran Canaria and comprise all or part of Basaltic Series II, III and IV of FUSTER *et al.* (1968). Much of this volcanism originated from local small volcanic centres.

On the basis of four K-Ar ages reported by ABDEL-MONEM *et al.* (1971) and five ages given by LIETZ and SCHMINCKE (1975) the latter authors suggested that this volcanism commenced about 2.8 m.y. ago and geological evidence indicates it continued until recent (prehistoric) times.

We have dated an additional ten samples from lavas of this last volcanic phase on Gran Canaria (Table 5). Samples GC71 and GC73 are from nephelinites collected southeast of Santa Lucia and stratigraphically above the Roque Nublo flows dated from La Fortaleza, previously discussed. Both rocks are well crystallized

TABLE 5 . POTASSIUM-ARGON AGES ON WHOLE ROCK SAMPLES OF LAVAS AND TWO INTRUSIONS FROM THE YOUNGER FORMATIONS OF GRAN CANARIA

| Field No | Lab. No. | K (wt. %) | Rad. $^{40}Ar$ ($10^{-12}$ mol/g) | $\frac{100\ \text{Rad.}\ ^{40}Ar}{\text{Total}\ ^{40}Ar}$ | Calculated Age (m.y.) $\pm$ 2 s.d. | Unit and Locality |
|---|---|---|---|---|---|---|
| Post Roque Nublo Group | | | | | | |
| GC60 | 74-226 | 1.289,1.294 | 0.349 | 7.3 | 0.15 $\pm$ 0.01 | Young valley fill. Near head of Barranco de Guayadeque |
| GC56 | 74-222 | 1.092,1.102 | 3.688 | 43.3 | 1.89 $\pm$ 0.05 | Altitude ∼ 1525 m |
| GC57 | 74-223 | 0.554,0.551 | 2.231 | 47.3 | 2.27 $\pm$ 0.06 | Altitude ∼ 1400 m |
| GC61 | 74-227 | 1.204,1.202 | 3.835 | 49.5 | 1.79 $\pm$ 0.05 | 10 m wide dike, 4 km SE of Tejeda |
| GC83 | 74-95 | 0.584,0.581 | 1.676 | 23.7 | 1.62 $\pm$ 0.05 | Altitude ∼ 800 m, 0.5 km W of La Pasadilla |
| GC84 | 74-97 | 0.811,0.812 | 3.156 | 39.2 | 2.18 $\pm$ 0.06 | 6 km NW of Ingenio |
| GC78 | 74-246 | 0.810,0.809 | 3.670 | 49.2 | 2.55 $\pm$ 0.05 | Caldera rim, NW of Tejeda |
| GC79 | 74-246 | 1.097,1.092 | 4.623 | 51.2 | 2.37 $\pm$ 0.04 | |
| GC73 | 74-240 | 1.107,1.098 | 5.301 | 25.0 | 2.70 $\pm$ 0.07 | Santa Lucia - Aguimes road, 2.7 km SE of Santa Lucia, GC73 several flows above GC71 |
| GC71 | 74-238 | 1.162,1.168 | 6.177 | 47.6 | 2.98 $\pm$ 0.07 | |
| Roque Nublo Group | | | | | | |
| GC53 | 74-219 | 1.169,1.171 | 7.095 | 61.0 | 3.40 $\pm$ 0.08 | Altitude ∼ 430 m La Fortaleza, 5.2 km SE of Santa Lucia |
| GC52 | 74-218 | 1.488,1.483 | 9.233 | 64.1 | 3.49 $\pm$ 0.08 | Altitude ∼ 415 m |
| GC65 | 74-232 | 4.500,4.455 | 30.42 | 81.8 | 3.81 $\pm$ 0.09 | Phonolite, Tejeda - St. Bartolomé road |
| GC76 | 74-243 | 1.436,1.435 | 9.915 | 62.1 | 3.88 $\pm$ 0,07 | Path to El Chorillo |
| GC1 | 74-166 | 4.097,4.118 | 28.26 | 61.3 | 3.86 $\pm$ 0.06 | Hauyne phonolite intrusion, 2 km W of Artenara |
| El Tablero Formation | | | | | | |
| GC24 | 74-190 | 0.809,0.802 | 7.867 | 54.0 | 5.48 $\pm$ 0.14 | Valley filling flow, 0.9 km from W Coast in Barranco de Tazartico |
| GC25 | 74-191 | 0.870,0.858 | 7.618 | 34.0 | 4.95 $\pm$ 0.13 | |

Note: All samples are basalts except GC1 and GC65 which are phonolites.

and reasonably fresh, and yield ages of 2.98 ± 0.07 m.y. and 2.70 ± 0.07 m.y. respectively. These data show that this younger volcanic phase commenced about 2.85 m.y. ago. Seven other samples from Basaltic Series II of FUSTER *et al.* (1968) give ages ranging from 2.55 to 1.62 m.y. (Table 5), in much the same range as those reported by ABDEL-MONEM *et al.* (1971) and LIETZ and SCHMINCKE (1975). It would appear that all samples with ages greater than 2.1 m.y. are olivine nephelinites (GC57, 78, 79, 84); sample GC61 (1.79 m.y.) is a melilite nephelinite and GC56 (1.89 m.y.) and GC83 (1.62 m.y.) are basanites containing both feldspar and nepheline. This information, together with data given by LIETZ and SCHMINCKE (1975) suggests that the nephelinite lavas, included by SCHMINCKE (1976) in his Llanos de la Paz Formation, were erupted mainly between about 2.85 and 2.1 m.y. ago, while the younger lavas are predominantly basanites.

The single sample (GC60) from Basaltic Series IV of FUSTER *et al.* (1968), included within the Calderilla Formation of SCHMINCKE (1976), gave an age of 0.15 ± 0.01 m.y. This sample was collected from a geomorphologically young valley filling flow which one of us (H-U.S.) believes is much younger than the measured K-Ar age. Conceivably this lava contains some excess argon which was not completely outgassed at the time of eruption.

## DISCUSSION AND CONCLUSIONS

The earlier work by ABDEL-MONEM *et al.* (1971) provided a physical time framework for the volcanic history of Gran Canaria. The present geochronological study has concentrated on the elucidation of the early subaerial history of this volcanic island, although much new data also are provided on rocks from the younger volcanic phases.

The most important result is that the main shield building, dominantly basaltic volcanism, comprising the lavas of the Guigui and Hogarzales Formations (equivalent to Basaltic Series I of FUSTER *et al.*, 1968) was confined to an extremely short interval between about 13.7 and 13.5 m.y. ago in the middle Miocene. Thus we suggest that the duration of the subaerial main shield building volcanism is unlikely to have exceeded about 0.5 m.y. We estimate that the total volume of basaltic volcanics erupted during this phase was about 1000 km$^3$. This volume is calculated on the basis of a cone of diameter 45 km, the present diameter of Gran Canaria at sea level, with the summit 2000 m above sea level. Main shield building lavas crop out at present to an altitude of 1000 m, but as the central part of the volcano has subsided because of caldera collapse, an original summit at about 2000 m altitude seems reasonable. Less than one fifth of the estimated volume of 1000 km$^3$ still remains owing to caldera collapse and erosion, and much of the original main shield is covered by a veneer of younger volcanics.

If it were assumed that the submarine part of Gran Canaria was also constructed during the main shield building phase the volume of volcanic material would be increased by a further 7400 km$^3$, using for the calculations a diameter of 90 km for the volcano at 2000 m below sea level.

The trachytes and rhyolites of the Mogan Formation, comprising perhaps 150 km$^3$ of material, were erupted with no detectable hiatus subsequent to the cessation of the shield building basaltic volcanism (Fig. 3). Major caldera collapse occurred at much the same time with filling of the caldera by silicic volcanics of the Mogan and Montaña Horno Formations. From our K-Ar data on Montaña Horno Formation rocks and the earliest member of the Mogan Formation we estimate that caldera collapse occurred at 13.4 ± 0.3 m.y. ago. This caldera formed after the eruption of the first voluminous ash flow following the main basaltic shield building phase, and probably was caused by the rapid emptying of subjacent magma chambers beneath the volcano. An important point is that large volumes of silicic magma had formed within the volcanic edifice and were erupted soon after cessation of basaltic volcanism. Such magmas are likely to be produced either by fractional crystallization of basaltic magmas or by partial melting of preexisting mafic volcanics within the volcanic pile; other geochemical data are necessary to distinguish between these possibilities.

Subsequent to the caldera collapse and partial infilling of the caldera by volcanics of the Montaña Horno and Mogan Formations mainly phonolitic rocks of the Fataga Formation were erupted intermittently from about 12.6 m.y. ago to about 9.7 m.y. ago. The volume of the Fataga Formation lavas is estimated to be in the vicinity of 100 km$^3$. Intrusives in the core of the volcano, again comprising about 100 km$^3$ and grouped together in the Tejeda Formation, were emplaced during a similar interval of time and probably were comagmatic with the Fataga Formation. We regard this activity as bringing to a close the main shield building phase of volcanism of Gran Canaria. The volcanism of the waning stages of activity may have continued until about 8.7 m.y. ago if the age of the phonolite GC5 is taken at face value.

Nephelinite lavas of the El Tablero Formation comprising much less than 1 km$^3$ in volume were erupted about 5 m.y. ago at about the Miocene-Pliocene boundary.

Resurgent volcanism, comprising the second magmatic phase, began about 4.4 m.y. ago with eruption of the Roque Nublo Group, which continued until about 3.4 m.y. ago. During this interval of time in the Pliocene an estimated 100 km$^3$ of silica undersaturated, mainly basanitic to tephritic eruptives were produced. Following a hiatus of less than

1 m.y., volcanism recommenced about 2.85 m.y. ago and continued until relatively recent times, forming a superficial cover on earlier rocks, with the total volume of eruptives probably much less than 10 km$^3$. In this third magmatic phase nephelinite magmas appear to be dominant in the period 2.85 to 2.1 m.y. ago, while basanitic magmas dominate the younger eruptions.

Alternatively the Roque Nublo and Post Roque Nublo eruptions could be thought of as a single long-lived resurgent phase, with the relatively small volume of the Post Roque Nublo eruptives representing the declining stages of activity of the volumetrically more important Roque Nublo volcanism (Fig. 5). It should be emphasized, however, that the nephelinites and basanites of the Post Roque Nublo Group are chemically distinct from the eruptives of the Roque Nublo Group.

A further model for the volcanic history of Gran Canaria was proposed by SCHMINCKE (1976) who suggested that two magmatic cycles can be recognized. The first cycle comprises the shield building basalts and subsequent silicic volcanism, concluding with eruption of small volumes of nephelinitic magmas about 5 m.y. ago. The second cycle consists of Roque Nublo and Post Roque Nublo lavas. It is stressed that all these models are simply a means of viewing the magmatic history in a manner that enables comparison to be made with volcanoes elsewhere, and that none is unique.

An important conclusion from this study of Gran Canaria is that this complex volcano has greater similarities to other basaltic volcanoes in oceanic regions than has hitherto been generally recognized. For example, the volcanoes of the Hawaiian Islands have a well documented history of a short lived subaerial main shield building basaltic phase, usually of duration less than 1 m.y., followed by eruption in a number of cases of more alkalic and silicic lavas within a few hundred thousand years of cessation of the shield building volcanism (MCDOUGALL, 1964). In several of the Hawaiian volcanoes minor resurgent volcanism comprising strongly undersaturated lavas (nephelinite, basanite etc.) took place after a hiatus of a few million years (MCDOUGALL, 1964; GRAMLICH *et al.*, 1971). The similarity in composition of the lavas of the resurgent volcanic phase in Hawaii and the youngest phase of volcanism in Gran Canaria (nephelinites and basanites) is particularly striking. The shield building lavas of the Hawaiian volcanoes are tholeiitic basalts, contrasting with the mildly alkalic basalts of Gran Canaria. However, many other volcanoes in the Pacific and Indian Oceans have been built rapidly and are composed of transitional to alkali basalts, not dissimilar to those of Gran Canaria. Examples include the volcanoes of Reunion (MCDOUGALL, 1971*a*; UPTON and WADSWORTH, 1966), Mauritius (MCDOUGALL and CHAMALAUN, 1969), the volcanoes of the Marquesas Islands (DUNCAN and MCDOUGALL, 1974), and those of the Society Islands (DUNCAN and MCDOUGALL, 1976).

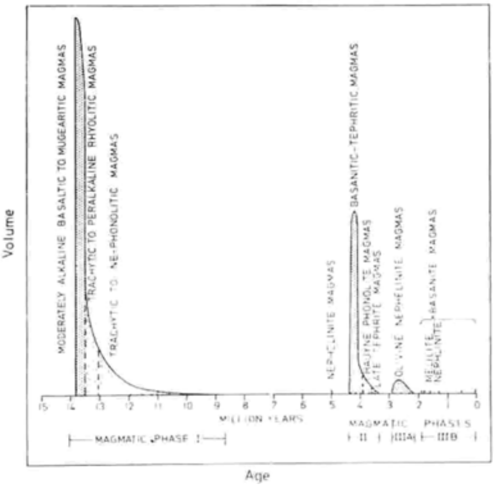

FIG. 5 - Schematic diagram showing duration, composition and approximate volumes of magmas of the magmatic phases on Gran Canaria. Note that relative volumes are not to scale; see text for estimates of volume.

Thus in many volcanoes in oceanic regions the main shield building phase of volcanism took place over a relatively short interval of time, generally less than one million years. This conclusion is of significance in terms of understanding how and why volcanoes are built in oceanic regions. The rapid construction of these volcanoes suggests that not only were large volumes of basaltic magma available but that there was a ready path for them to reach the earth's surface. A possible explanation for the observations is that tensional forces in the oceanic lithosphere (GREEN, 1971; McDOUGALL, 1971*b*; TURCOTTE and OXBURGH, 1973) causes fracturing and release of pressure, allowing diapiric upwelling of upper mantle peridotite from the low velocity zone with concomitant production by partial melting of large volumes of basaltic magma, which erupts to build large volcanic edifices. In many regions these volcanoes form roughly linear volcanic chains which exhibit a monotonic decrease in age along the chain toward the nearest mid-ocean ridge. This has given rise to the concept of mantle hot spots or plumes with the source for the magmas lying below the moving lithospheric plate on which the volcanoes are constructed (WILSON, 1963; MORGAN, 1972). These ideas have relevance to the origin of the Canary Islands as they collectively form a roughly linear group of volcanoes which become progressively younger in a westerly direction toward the Mid Atlantic Ridge if the older basaltic lavas are identified as the main shield building phase (ABDEL-MONEM *et al.*, 1971) as illustrated in Fig. 6. SCHMINCKE (1973) and ANGUITA and HERNAN (1975) have examined the available data from the Canary Islands in the light of a hot spot origin and conclude that the velocity of migration of the centre of volcanism is too erratic to provide a convincing case for the hypothesis to be applicable. Anguita and Hernan found apparent velocities of migration of the centre of volcanism between adjacent volcanoes ranging from 0.6 to 26.7 cm/year, with all but one lying between 0.6 and 2.8 cm/year. The higher velocity of 26.7 cm/year was calculated for the migration of volcanism from Fuerteventura to Gran

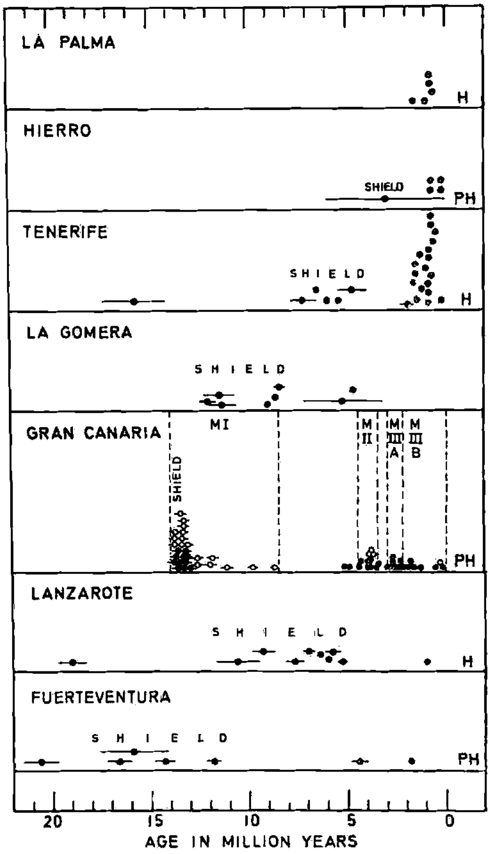

FIG. 6 - Comparison of age data on Miocene and younger formations from all the Canary Islands. Data or all islands, except Gran Canaria, from ABDEL-MONEM *et al.* (1971, 1972). H = historic eruption; PH = sub-recent eruptions. Some older ages are available for Fuerteventura (ABDEL-MONEM *et al.*, 1971) but are not plotted. Data for Gran Canaria from this study and LIETZ and SCHMINCKE (1975). For Gran Canaria solid dots represent ages on basaltic rocks, whereas unfilled circles represent ages on trachytes, rhyolites, phonolites etc. Error bars are shown in those cases where the quoted error is significantly larger than the size of the dots. Duration of magmatic phases are indicated for Gran Canaria. Modificated from SCHMINCKE (1976).

Canaria, but if the age of the main shield building phase for the latter, found in this study, of about 13.7 m.y. is accepted this figure becomes 4.7 cm/year. However, because our data on the age of the main shield building volcanism on Gran Canaria differ considerably from those of ABDEL-MONEM *et al.* (1971) it may well be that similar problems exist in relation to the ages of the older basalts on the other Canary Islands. Clearly additional age data are required on all the older basaltic, main shield building phases of the Canary Island volcanoes to be able to determine with confidence whether the migration of volcanism with time is consistent or otherwise with hot spot, propagating fracture or other models for the origin of volcanic island chains.

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## APPENDIX

### SAMPLE LOCALITIES AND PETROGRAPHY

*Guigui Formation* (Table 2)

GC7: Alkali basalt dike about 1 m wide, Barranco de Guigui, 125 m above sea level, 0.5 km SE of El Puerto, west coast. Abundant titanaugite and olivine phenocrysts set in well crystallized intergranular groundmass; several percent pale green intersertal mineraloid or layer silicate.

GC6: Alkali basalt lava flow, cut by GC7, same locality. Abundant titanaugite and olivine phenocrysts with some plagioclase and iron oxide microphenocrysts in well crystallised but fine grained base. Minor zeolite filling vesicles.

GC6: Alkali basalt lava in Barranco de Tazartico, 0.9 km east of coast below GC24, 25. Some olivine and clinopyroxene phenocrysts in basaltic, well crystallized groundmass. Thin coating of layer silicate on vesicles.

GC28: Basalt lava flow in north cliff of mouth of Barranco de Tazartico on west coast. Rare olivine and pyroxene phenocrysts and common plagioclase microphenocrysts in well crystallized base. Layer silicate coating small vesicles.

GC29: Basalt lava, same locality as GC28 but from cliff on south side of Barranco at coast. Similar to GC28 but groundmass very fine grained.

*Hogarzales Formation* (Table 2)

GC22: Hawaiite lava on road San Nicholas to Agaete, 300 m from 60 km post toward 61 km post, altitude 420 m. Abundant microphenocrysts of clinopyroxene, plagioclase, iron oxide in extremely fine-grained, fresh groundmass of same minerals. Minor brownish mineraloid in rare vesicles.

GC23: Hawaiite flow, 200 m down road from GC22 at altitude 400 m. Similar to GC22 but coarser grained groundmass, and minor (few percent) poorly crystallized mesostasis showing incipient alteration.

GC15: Hawaiite flow, about 100 m south of Mirador de Balcon, about 200 m south of km 61 post on San Nicolas-Agaete road. Aphyric, slightly oxidized, fluidal lava with incipient alteration to layer silicates.

GC13: Hawaiite flow, altitude about 100 m, about 600 m due north of Puerto de la Aldea, west coast. Finely vesicular with coatings of yellow layer silicate. Microphenocrysts of altered olivine, fresh clinopyroxene and plagioclase in extremely fine-grained to cryptocrystalline base.

GC14: Hawaiite flow, some 200 m due north of Puerto de la Aldea. Virtually identical to GC13 but yellow layer silicate even more abundant in vesicles.

GC11: Hawaiite lava flow, Barranco de Guigui, 250 m altitude, about 1 km east of El Puerto, west coast. Few altered olivine phenocrysts and few percent plagioclase and clinopyroxene microphenocrysts in very fine grained well crystallized groundmass with rare ?zeolite filled vesicles.

*Mogan Formation* (Table 3)

GC42: Comenditic ignimbrite E, mouth of Barranco de Taurito, southwest coast; see SCHMINCKE (1976, Fig. 43). Anorthoclase phenocrysts but some edenite in variably crystallized groundmass of anorthoclase, quartz, aegirine and alkali amphibole.

GC45: Comenlitic trachytic ignimbrite A, road cutting on west side of Barranco de Taurito. About 10 % anorthoclase and plagioclase phenocrysts in somewhat altered glassy to cryptocrystalline groundmass.

GC44: Trachybasalt T4 on west side of Barranco de Taurito. Minor clinopyroxene and iron oxide microphenocrysts in very fine grained base of iddingsitized olivine, fresh plagioclase, clinopyroxene and iron oxide. Pale brown layer silicate occurs in small vesicles. See SCHMINCKE (1976), sample C.N. 55 for chemical analysis.

GC43: Pantelleritic ignimbrite X in Barranco de Taurito about 300 m from coast. Very abundant anorthoclase phenocrysts with some amphibole and sphene in fine grained to cryptocrystalline base. See SCHMINCKE (1976), sample C.N. 1022 for chemical analysis (field sample nos. 715 and 697 in SCHMINCKE, 1976, are interchanged).

GC39: Alkali rhyolite lava, Barranco de Mogan, 1.6 km from southwest coast at road junction to Puerto de Mogan. Few percent anorthoclase phenocrysts in cryptocrystalline base.

GC38: Alkali rhyolite dike intruded into Hogarzales Formation. On road San Nicolas to Mogan, 1 km north of Veneguera. Several percent anorthoclase phenocrysts and rarer augite and hypersthene and iron oxide set in cryptocrystalline base.

GC19,20: Alkali rhyolitic ignimbrite P1 grading into basalt. Road San Nicolas-Agaete at Anden Verde, altitude 530 m. Very abundant (30 % +) anorthoclase phenocrysts with oligoclase cores, and about 2 % edenitic amphibole set in an altered glassy to cryptocrystalline base.

*Montaña Horno Formation* (Table 3)

GC37: Margin of rhyolite body, base of Montaña Horno near road Mogan to San Nicolas. About 50 m from caldera magin in caldera filling sequence. Few percent anorthoclase phenocrysts in cryptocrystalline base.

GC35: Green pumice tuff at base of Montaña Horno on Mogan - San Nicolas road, adjacent to caldera perimeter fault and within caldera. About 10 % anorthoclase crystals in cryptocrystalline base.

*Fataga Formation* (Table 4)

GC80: Phonolite flow at Punta del Palo on east coast road about 6.5 km south of Las Palmas toward Gando. About 10 % of anorthoclase phenocrysts in a fluidal fine grained groundmass of alkali feldspar, slightly altered nepheline and small needles of aegirine.

GC46,47: Nepheline phonolite lava, between 11 and 12 km posts on Maspalomas - Fataga road, about 5 km north of Maspalomas, altitude about 350 m. About 2 % of anorthoclase phenocrysts in a poorly crystallized, somewhat altered groundmass.

GC41: Trachyphonolite lava L1, in small barranco between Barranco de Taurito and Barranco de Mogan, about 150 m east of 83 km post, near southwest coast. Sporadic phenocrysts of anorthoclase in fluidal fine grained base.

GC40: Trachytic ignimbrite G, overlooking Puerto de Mogan on coast road, 100 m west of 83 km post, altitude about 80 m. About 10 % anorthoclase phenocrysts in rather inhomogeneous poorly crystallized base.

*Tejeda Formation* (Table 4)

GC5: Nepheline phonolite dike about 11 m wide intruding syenite body, about 200 m downstream from Paralillo dam. Aphyric rock with aegirine and alkali amphibole in rather poorly crystallized groundmass of anorthoclase and nepheline with some iron oxide.

GC3,4: Syenite body just below Paralillo dam on road Artenara - San Nicolas. Medium to coarse grained unmixed alkali feldspar and about 5 % fresh biotite with some carbonate, fluorite, leucoxene and layer silicates. See SCHMINCKE (1976) sample 1375 for chemical analysis.

*El Tablero Formation* (Table 5)

GC24,25: Olivine nephelinite intracanyon flow overlying gravel, Barranco de Tazartico, 900 m from west coast. About 10 % olivine phenocrysts with some iron oxide and clinopyroxene microphenocrysts in an intersertal — intergranular groundmass of titanaugite, iron oxide and somewhat altered ? glass or nepheline.

*Roque Nublo Group* (Table 5)

GC53: Tephrite lava flow, La Fortaleza, Barranco de Tirajana, 5.2 km southeast of Santa Lucia, altitude 430 m. Phenocrysts of clinopyroxene with less common oxidized kaersutite, iron oxide and apatite in a fine grained, not well crystallized groundmass of clinopyroxene, plagioclase, iron oxide and possibly some alkali feldspar, zeolite and layer silicate.

GC52: Tephrite lava, just below GC53 at same locality. Petrographically very similar to GC53, but slightly fresher.

GC65: Phonolite lava flow at least 15 m thick, on road Tejeda to San Bartolomé (C-811), 300 m beyond 52 km post. Rare anorthoclase and clinopyroxene phenocrysts in fluidal groundmass of feldspar and small clinopyroxene. Incipient alteration of groundmass.

GC76: Alkali basalt lava flow, south side of Barranco de Siberio along foot path to El Chorillo at about 800 m altitude. Second flow above base of sequence in Mesa de Junquillo Formation. Less than 10 percent phenocrysts which are olivine, titanaugite, plagiocase, oxidized kaersuite, iron oxide and apatite. Intergranular groundmass of altered olivine, clinopyroxene, plagioclase and iron oxide. Somewhat vesicular rock with thin layer silicate coating.

GC1: Hauyne phonolite stock, along road Artenara-San Nicolas, 2 km west of Artenara. Minor feldspar and clinopyroxene phenocrysts in fluidal groundmass of feldspar, sodic clinopyroxene, iron oxide, hauyne and apatite. Rock has slightly altered appearance.

*Post Roque Nublo Volcanics Group* (Table 5)

GC60: Basanite lava at head of Barranco de Guayadeque. Very young intracanyon flow from La Calderilla. See SCHMINCKE (1976) sample 1433 for analysis. Abundant phenocrysts of olivine and clinopyroxene in a very fine grained, well crystallized intergranular fresh, basaltic groundmass.

GC56: Basanite lava at Morro Garañon, 500 m east of rim of Caldera de los Marteles, north wall of Barranco de Guayadeque, altitude 1525 m. Abundant fresh olivine phenocrysts set in an intergranular well crystallized groundmass in which occur some large plagioclase crystals containing small clinopyroxene crystals.

GC57: Olivine nephelinite lava at bottom of Barranco de Guayadeque near its head, altitude 1400 m. About 15 % fresh olivine phenocrysts and some clinopyroxene phenocrysts in a groundmass of clinopyroxene, iron oxide and much nepheline which shows slight alteration.

GC61: Melilite nephelinite dike, 10 m wide, about 100 m northeast of road junction Tejeda-Pozo de las Nieves-Teide, 1860 m above sea level. Abundant fresh olivine phenocrysts with some titanaugite and melilite phenocrysts in intergranular well crystallized groundmass of clinopyroxene, iron oxide, perovskite and nepheline.

GC83: Basanite lava, 250 m northwest of 8 km post on road Ingenio to La Pasadilla, at about 800 m altitude. Abundant olivine phenocrysts and much less common titanaugite and iron oxide in fresh, well crystallized groundmass of clinopyroxene, plagioclase and iron oxide.

GC84: Olivine nephelinite lava, several flows below GC83 on same road about 200 m west of 8 km post. Olivine phenocrysts with iddingsite rims, some clinopyroxene phenocrysts in a fine grained, well crystallized intergranular base of clinopyroxene, iron oxide and nepheline.

GC78,79: Successive olivine nephelinite lavas at Mirador, along road Cruz de Tejeda-Artenara, 1624 m above sea level. Abundant olivine phenocrysts, some clinopyroxene set in relatively fresh, fine grained, well crystallized groundmass of clinopyroxene, nepheline and iron oxide.

GC73: Olivine nephelinite lava flow, 2.9 km southeast of Santa Lucia on road to Aguimes near 15 km post, altitude 770 m. Abundant olivine with a groundmass of clinopyroxene and iron oxide set poikilitically in large nepheline crystals. Well crystallized and fresh.

GC71: Olivine nephelinite lava flow, 2.7 km southeast of Santa Lucia near big bend, altitude 755 m. Several flows stratigraphically below GC73. Petrographically similar to GC73 but vesicular and has some clinopyroxene phenocrysts in addition to olivine.

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