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POTASSIUM-ARGON AGES, VOLCANIC STRATIGRAPHY, AND GEOMAGNETIC POLARITY HISTORY OF THE CANARY ISLANDS: LANZAROTE, FUERTEVENTURA, GRAN CANARIA, AND LA GOMERA†

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ABSTRACT. In order to produce a quantitative within and between-island stratigraphic framework for four of the Canary Islands, K-Ar ages and paleomagnetic polarities have been determined for 51 igneous bodies. The following major conclusions result for the respective islands:

1. On Lanzarote, lava sequences of the Farmara massif in the north and Los Ajaches massif in the south overlap slightly in age and range in age from 6 to 12 m.y. One lava flow at the southern limit of the island is at t = 19.0 ± 0.68 m.y. equivalent in age to a similar lava at the northern end of Fuerteventura, immediately to the south.

2. Hornblende and biotite separated from a syenite of the basement complex of Fuerteventura provide ages of 20.8 and 18.4 m.y. respectively. An aegerine-augite separated from an alkali syenite in the basement complex provides a measured age of 38.6 m.y. A low grade metamorphic rock north of the main basement complex provides a K-Ar age of 35.3 m.y. The basement complex therefore precedes t = 35 m.y. but is unlikely to predate the Mesozoic sediments of west-central Fuerteventura.

Basalts of the Jandia peninsula were extruded between t = 17 and 14 m.y., preceding the basalt sequences of the east-central part of Fuerteventura by 3 m.y. or more, and are equivalent in age to the older lavas of the northwest coast of Gran Canaria.

3. Two long-duration volcanic phases are present on Gran Canaria. The older basalts, rhyolites, rhyolitic and trachytic ignimbrites, and phonolites are limited to the period t = 16 to 9 m.y. and are separated from an explosive volcanic series and basalts by a quiescent period lasting on the order of 5 m.y., during which carbonate-rich sediments were deposited.

4. On the island of La Gomera, quiescence occurred between t = 8.0 and 5.2 m.y., when uplift, tilting, and substantial erosion occurred. The basement complex of this island was intruded in part 12 m.y. ago at about the same time as the oldest outcropping extrusive activity began. These extrusives span up to 4 m.y. Horizontal lavas were extruded onto the eroded basement between t = 5.2 and 4.7 m.y.

The paleomagnetic data reveal detection of the Jaramillo event on Lanzarote, the Matuyama reversed epoch on Gran Canaria, and an event within the Gauss epoch on Gran Canaria. Polarity data in each island are amenable to use in fine within-and between-island stratigraphic correlation.

Although hiatuses up to 5 m.y. long are present in some islands, when all four islands are considered as a whole, volcanism of diverse petrological type has occurred throughout much of the last 20 m.y.

INTRODUCTION

Like most geological processes, volcanism has as one of its essential characteristics the dimension of time. The phenomenon cannot be completely described without reference to rates or correlative time markers. The virtual absence of useful fossiliferous sediments in most volcanic sequences has severely limited the investigation of this aspect of volcanic

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*** Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York 10964. Present Address: Lunar Receiving Laboratory, Dept. TN, Manned Space Center, Houston, Texas 77058 processes. Relatively little is known about the production rates of volcanic liquid and/or the continuity of these rates. Furthermore, the correlation of eruptive events between closely associated volcanoes is only poorly understood in most cases. In a few oceanic islands, the application of potassium argon dating to young volcanic materials along with the development of a geomagnetic polarity time scale (McDougall, 1964; Cox and Dalrymple, 1966; Cox, Hopkins, and Dalrymple, 1966; McDougall and Wensink, 1966; Chamalaun and McDougall, 1966; McDougall and Chamalaun, 1966; Baker, Gale, and Simons, 1967; Moorbath, Sigurdsson, and Goodwin, 1968; and Dalrymple and Cox, 1968) has shown that structurally and chemically similar volcanic regions can differ very significantly in their rates of evolution and growth. These studies suggest that the span of time covered by the development of similar volcanic edifices can differ by more than an order of magnitude.

In order to determine the time relations of a variety of rock types in a single island and compare closely associated volcanoes of different types between and within a group of islands, we have investigated the volcanic stratigraphy of all the major Canary Islands (fig. 1) using the K–Ar dating method. In addition, the paleomagnetic polarities of the dated bodies have been measured. These may assist in determining fine correlation between stratigraphic units, as well as contributing to definition of the geomagnetic polarity history. In this first paper, we present the results from Lanzarote, Fuerteventura, Gran Canaria, and La Gomera (fig. 1).

GEOLOGICAL BACKGROUND

The Canary Islands (fig. 1) straddle a oceanic-continental transitional zone. Rothe and Schminke (1968) believe that Lanzarote and Fuerteventura have geological affinities with the adjacent African coast. This suggestion is supported in part by the seismic refraction results of Dash and Bosshard (1969) and the gravity data of MacFarlane and Ridley (1969). In contrast, the western Canary Islands are over base-

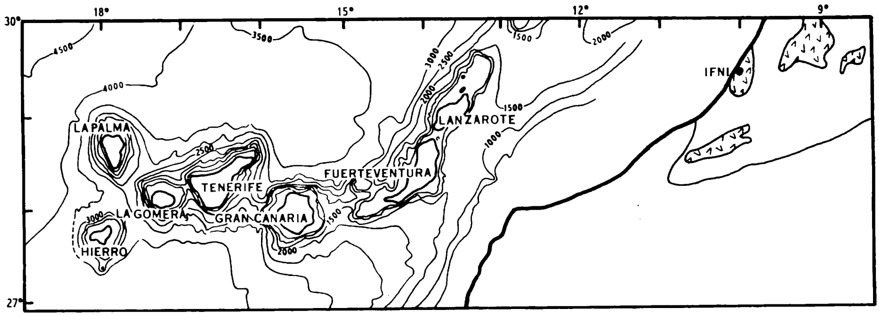

Fig. 1. Map showing location of the Canary Islands, relative to the adjacent African coast, and regional bathymetry (Dash and Bossard, 1969). Precambrian volcanics of Anti-Atlas of Morocco indicated by check pattern. Bathymetric contours in meters.

ment which is deeper and seismically oceanic (Dash and Bosshard, 1969). This division of the Canary Islands into two contrasting zones is further supported by the Dietz and Sproll (1970) analysis of pre-continental drift configurations in the North Atlantic: Lanzarote and Fuerteventura are envisaged as part of the African continent prior to the initiation of drifting. At this time, as Nafe and Drake (1969, fig. 16) and LePichon and Fox (1971) point out, the present sites of the Canary Islands and the New England seamounts (which are probably Cretaceous in age) were colinear and adjacent. Their reconstruction of the North Atlantic was made using the limits of the magnetic "quiet zone" or marked boundary between marine magnetic anomalies of noticeable amplitude (typical of oceanic regions) and low amplitude anomalies (typical of continental shelf areas) in the Atlantic (Heirtzler and Hayes, 1967). This boundary is thought to pass between Tenerife on the east and Hierro (fig. 1) on the west. The age of this boundary, which probably arises from layer 2, is thought to be either Cretaceous or Permian, since during these epochs magnetic polarity changes are much less common than in other parts of the geological time scale of comparable duration, and therefore any process of dike injection and crustal spreading would not create bodies of varying polarities and a resultant large sea-level magnetic anomaly fluctuation. Such interpretations can clearly be tested by age measurements on the Canary Islands.

Rona and Nalwalk (1970) propose that separation of the eastern pair of islands from Africa was during the early Cenozoic, possibly in association with the Eocene tectonic activity which was involved with the creation of the Atlas Mountains of Morocco. It follows that the western islands would be much younger than the possible continental remnants forming at least the nucleii of the eastern islands.

Several workers have attempted to synthesize the volcanic stratigraphy of the major islands into a general between-island stratigraphic column, but except for five commercially obtained K–Ar ages from a very restricted part of Fuerteventura (Rona and Nalwalk, 1970) no quantitative age measurements have been published. In this presentation, we shall discuss the detailed stratigraphic relationships in each island during interpretation of our results.

METHODS OF STUDY

Samples were taken in three different field seasons. During the initial survey in 1965, at least two geographically oriented cores were drilled from thirty-eight lavas on Lanzarote, forty lavas on Gran Canaria, and eighteen lavas on La Gomera, as part of a paleomagnetic survey of five of the Canary Islands. These paleomagnetic results have already been published (Watkins, Richardson, and Mason, 1966a). Up to four oriented lumps and a single large unoriented sample were taken from twenty-five other bodies on Gran Canaria in 1966. As many as eight cores per body were also drilled from twenty-three units on Fuertaventura and La Gomera. Similar additional coverage was obtained for Lanzarote. On LaGomera, the basement complex and some additional lavas were also sampled. During 1968, resampling of three and sampling of a final thirty units in key stratigraphic positions were carried out on Gran Canaria. In this way, the major stratigraphic units on Gran Canaria (table 1) were sampled, and extensive vertical coverage was obtained on the other three islands. The site locations of the specimens chosen for both K:Ar and paleomagnetic analyses are shown in figures 2A, 3A, 4A, and 5A and are detailed in the appendix. The sites are also given on sketches of the most recent available geological maps in figures 2B, 3B, 4B, and 5B.

Conventional transmitted light thin-section examination has been made on at least one sample from each dated body.

Individual potassium measurements were made on 0.1 to 0.5 g aliquots of the powdered portions of the samples (200 mesh). During the course of this study potassium was determined by two methods: isotope dilution and atomic absorption techniques. The uncertainty in the potassium analyses was estimated from duplicate analyses on some of the samples reported here as well as standard rocks and minerals. The uncertainties are ± 2 percent and ± 4 percent for the isotope dilution and atomic absorption methods, respectively.

The argon measurements were made on 3 to 10 g aliquots of pea-size or 20 to 40 mesh size crushed samples depending on their grain size.

TABLE 1

Correlation of the three published stratigraphic classifications of Gran Canaria volcanic rocks

(A)	(B)	(C)
Bourcart and Jeremine (1937)	Hausen (1962)	Fuster and others (1968b)
Arucas tahitite Very Recent basalts	Quaternary and Recent basalts	Basaltic Series IV
Valley basalts Plateau basalts	Post-Miocene basalts	Basaltic Series III Basaltic Series II
Vindobodian ordanchites	Highly Na-alkaline phonolitic lavas	Ordanchitic Series
Nublo, Dehesa . . . et cetera breccias	Roque Nublo agglomerates and interfingering tephritic lava effusions	Roque Nublo Series
Vindobodian basanites		Pre-Roque Nublo Series
Gray rhyolites Cinerites (canto blanco) White phonolites and trachytes	Puzzolane (canto blanco) Phonolite lavas	Phonolitic Series
Syenites Rhyolites and trachytes Phonolites	Tableland basaltic formation	Syenetic-Trachytic Complex
Old basalts	Dislocated trachytes	Basaltic Series I
	Syenitic plutonic bosses Young trachytes	

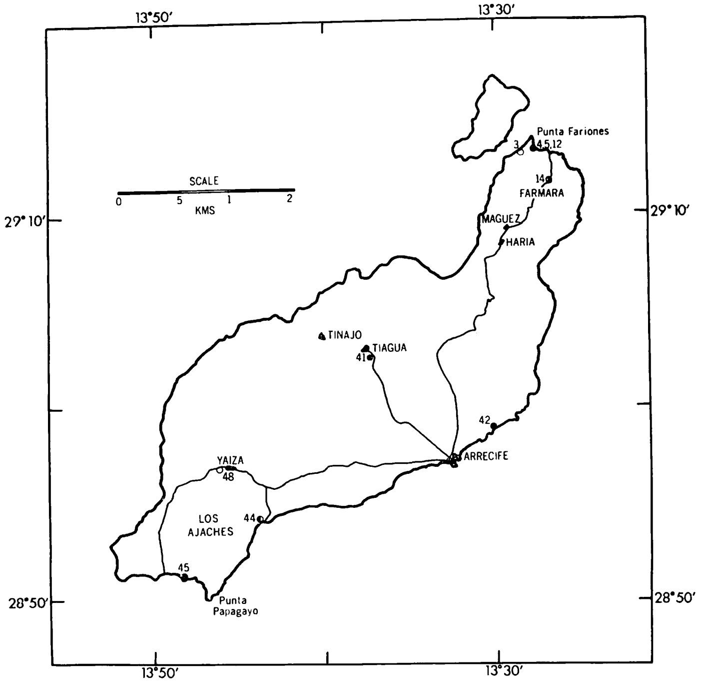

Fig. 2A. Locations and numbers of sample sites on Lanzarote. Major roads and settlements shown. For details of locations, see appendix. Paleomagnetic polarities of units (table 3) indicated as follows: open circle = reversed polarity; solid circle = normal polarity; split circle = transitional (virtual geomagnetic pole equatorward of 30° lat).

The extraction of argon was performed by the direct fusion technique under ultra high vacuum, using RF-induction heating. The two extraction systems used during this study were described by McDowell (1966). It was found that the removal of an alumina crucible, primarily used as a radiation shield, greatly reduced the argon blank of the systems. It was replaced by a spun-Mo crucible to house the sample to be fused, surrounded by 0.010 in. Mo-sheet as a radiation shield. This new arrangement reduced the argon blank in the systems by a factor of about 10.

The radiogenic argon content of the rock and mineral samples were determined by isotope dilution techniques and mass spectrometry.

During the first half of this study the Ar^{38} spikes were prepared and calibrated by the procedures described by Reynolds and Spira (1966). Subsequently, an Ar^{38} spiking technique using a bulb tracer and an all metal pipetting double valve with 0.1 cc interval volume was adopted. Ar^{38} aliquots taken by the double valve were calibrated against known volumes of air argon as well as against the U.S. Geol. Survey standard muscovite P-207.

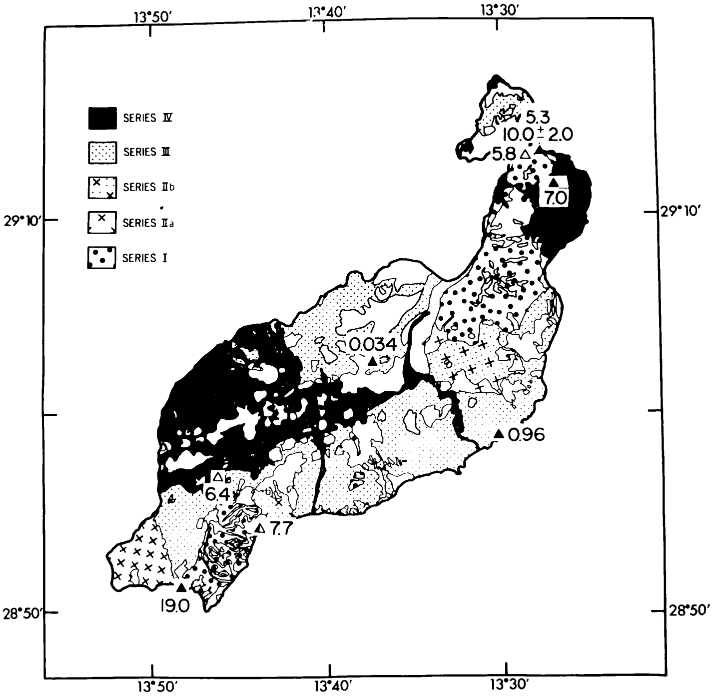

Fig. 2B. K-Ar ages of sampled units on Lanzarote, in millions of years (table 2). Geology after Fuster, Santin, and Sagredo (1968). Sample sites shown as triangles. Paleomagnetic polarities of units (table 3) indicated as follows: open triangles = reversed polarity; solid triangles = normal polarity; split triangle = transitional (see fig. 2A caption for explanation).

In this study the errors in the calculated K:Ar age, were estimated using the following formula proposed by Cox and Dalrymple (1967):

$$\sigma = \left[(\sigma\ k)^2 + (\sigma\ x)^2 + (\sigma_{38}{}^{40})^2 \left(\frac{1}{r}\right)^2 + (\sigma_{38}{}^{36})^2 \left(\frac{1-r}{r}\right)^2 \right]^{1/2}$$

where:

$\sigma\ k$ = percent error in k determinations
$\sigma\ x$ = percent error in the calibration of Ar^{38} spike
$\sigma_{38}{}^{40}$ = percent error in the measurement of 40/38 ratio
$\sigma_{38}{}^{40}$ = percent error in the measurement of 36/38 ratio
r = fraction of the radiogenic argon.

σ k is estimated to be 0.6 percent, on average, based on replicate determinations of inter-laboratory minerals and rocks. σ x was found to be 0.6 percent from several calibration runs made against known volumes of argon extracted from air and also against P-207 standard muscovite. $\sigma_{38}{}^{40}$ was estimated from the measurements of the Ar^{40}/Ar^{38} ratio during calibration runs. The average standard deviation of such measurements in this laboratory over the past 10 years is 0.7 percent (Mc-

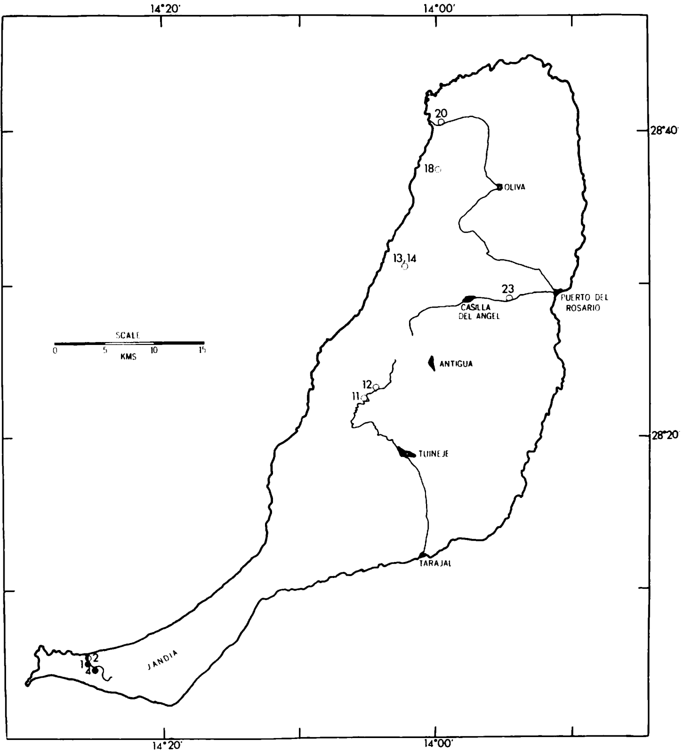

Fig. 3A. Locations and numbers of sample sites on Fuerteventura. Major roads and settlements shown. See figure 2A caption for additional explanation.

Dowell, 1966). $\sigma_{38}{}^{36}$ is estimated here as 2 percent. This is based on the observed average during the course of this study. It is clear from the above formula that the variations in the precision of the K:Ar dates are due mainly to the atmospheric argon contaminations. In replicate analyses the average value of r was used for the estimation of the error. The errors based on replicate analyses are larger than those estimated from the above formula. Usually the lower radiogenic argon contents in a replicate set were accompanied by large atmospheric corrections.

Spinner and astatic magnetometers were used to determine the directions and other functions of the natural remanent magnetism. All specimens were subjected to demagnetization in at least three different alternating magnetic fields, using a bi-axial tumbling system (McElhinny, 1966). The experimental method therefore places our samples in category III in the scheme of Doell, Dalrymple, and Cox (1966) for polarity:age work. Conventional statistical analyses, as described by Watkins and Richardson (1968) and other authors, were made to arrive at a measure of the polarity during the initial cooling of the lavas. We define our polarities as normal for virtual geomagnetic latitudes higher than 30°

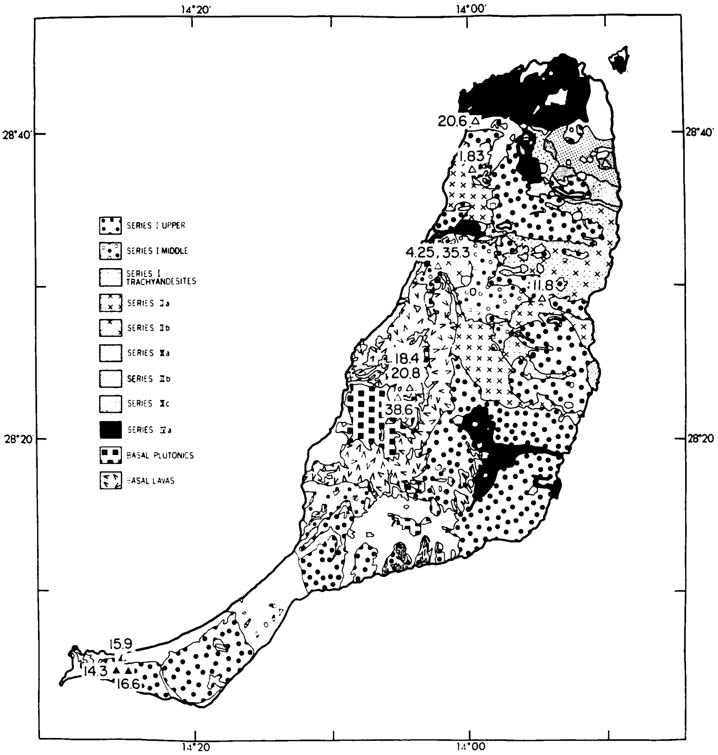

Fig. 3B. K-Ar ages of sampled units on Fuerteventura, in millions of years (table 2). Geology after Fuster and others (1968a). See figure 2B caption for additional explanation.

north, intermediate for latitudes lower than 30°, and reversed for virtual geomagnetic latitudes higher than 30° south.

RESULTS

The K–Ar age determinations are given in table 2 and in figures 2B, 3B, 4B, and 5B. Paleomagnetic results are reported only for those units that have been dated. These are given in table 3 and incorporated diagramatically into figures 2 to 5. Detailed petrographic descriptions of the thin sections from each body are not included in this report but are available from the authors on request.

DISCUSSION

We discuss the results in the following order: first we examine the K–Ar ages obtained for each stratigraphic unit using the most recent stratigraphic terminology. The results will then be combined for an inter island comparison, and finally the resulting polarity and age data will be combined for comparison with the established geomagnetic history.

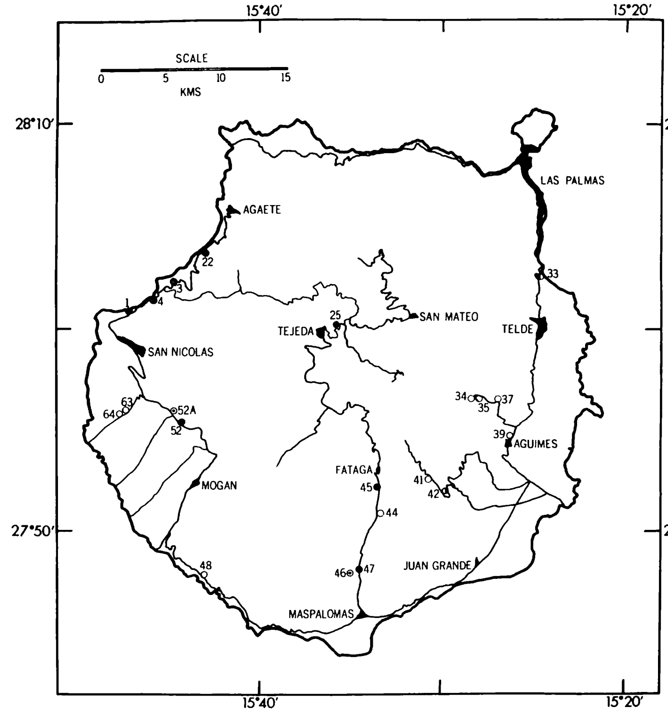

Fig. 4A. Locations and numbers of sample sites on Gran Canaria. Major roads and settlements shown. See figure 2A caption for additional explanation. Sites of two unoriented samples (no polarity determinations possible) each shown as circled dot.

In all cases, when the rock unit or body is referred to as a number, the number corresponds to that in the respective site location diagram (figs. 2A, 3A, 4A, or 5A). The original field number identification is also included in tables 2 and 3 and the appendix.

Lanzarote (fig. 2)

The stratigraphy of this island consists of two greatly different volcanic sequences: first a series of old basalts exposed in the Farmara massif in the north and the Los Ajaches massif in the south, and secondly the wide-spread Quaternary and Recent flows and pyroclastics that cover the remaining part of the island (fig. 2B). The geology and petrography of both the older and younger rocks have been described in some detail by Hausen (1959), Rothe (1966, 1967), and Fuster, Santin, and Sagredo (1968). The younger volcanic sequences are divided into a number of subseries by their relation to Recent terraces. Since we have not attempted to investigate the younger eruptions in detail, we will not consider this subdivision further here. The older basalts [Tableland (Hausen, 1959) or Series I (Fuster, Santin, and Sagredo, 1968)] in the two extremities of the island, are petrographically and structurally similar. They consist predominantly of horizontal to sub-horizontal picritic and olivine basalts.

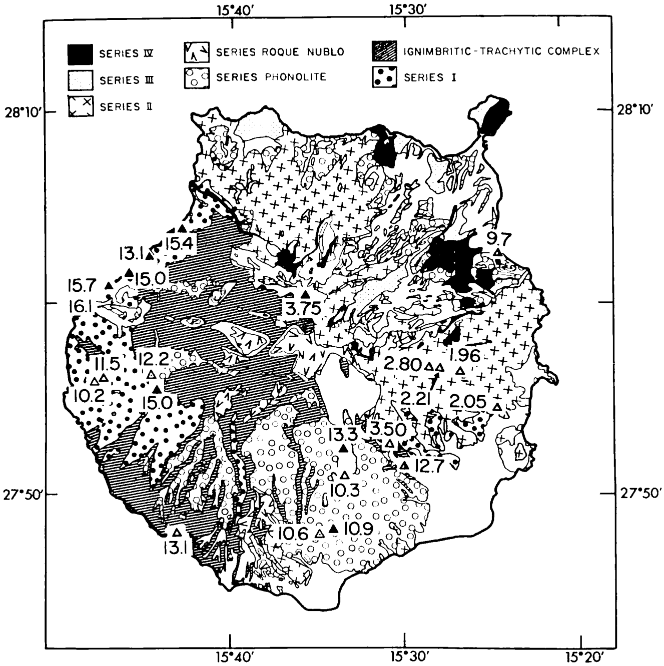

Fig. 4B. K-Ar ages of sampled units on Gran Canaria in millions of years (table 2). Geology after Fuster and others (1968b). See figure 2B caption for additional explanation. Sites of two unoriented samples (no polarity determinations possible) each shown as open triangle with central dot.

Red soils and disconformities suggest that this section is the result of an intermittent sequence of eruptions. A disconformity between the older basalts (Series I) and the oldest rocks on the island has been suggested by Fuster, Santin, and Sagredo (1968), who find that trachyte intrusion into this basalt series, in the Punta Papagayo region, is unconformably overlain by younger Series I basalts.

Samples from six different localities in the older basalts have been investigated in this study. Unfortunately, even after selection of the freshest samples from a much larger collection, most of the samples are partially altered. Olivine is almost always altered to iddingsite. Many of the samples also contain some chlorite. This alteration is particularly evident in the rocks from the Punta Fariones scarp at the northern point of the island. Ages from this region are thus somewhat uncertain due to possible argon loss. The oldest age (LZ-45, 19 m.y.) was found for the materials just west of Punta Papagayo. Even though these rocks show extensive evidence of cataclastic deformation, they are quite fresh in hand specimen. Microscopic examination does not reveal any low temperature minerals such as albite, chlorite, or zoisite. Samples from two other localities in the Los Ajaches area are much younger. Sample LZ-44, from the same elevation as LZ-45, gives an age of 7.7 m.y. A

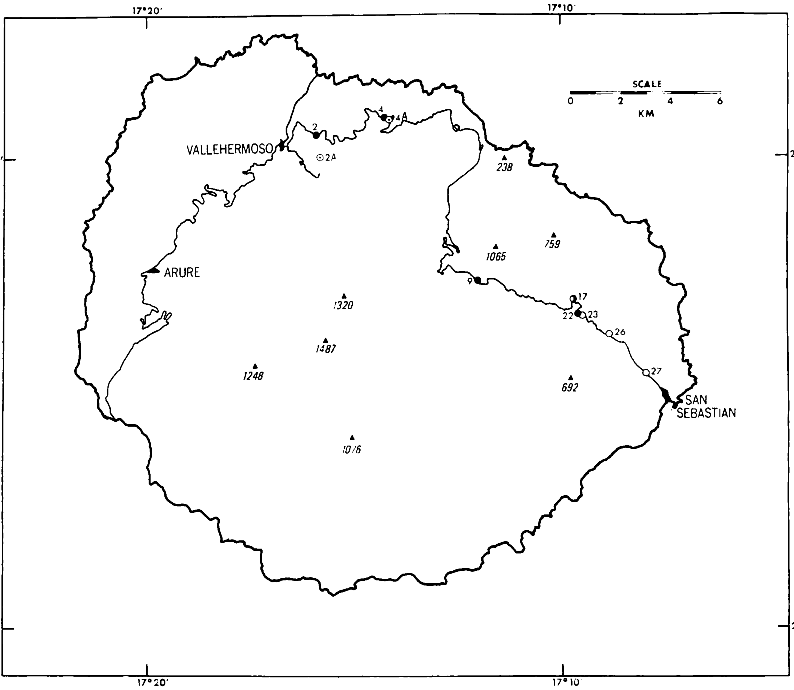

Fig. 5A. Location and numbers of sample sites on La Gomera. Major roads, settlements, and topographic peaks (height in meters) shown. See captions to figures 2A and 4A for additional explanations.

second sample about 175 m above sea level (LZ-48) and stratigraphically above LZ-44 gives an age of 6.4 m.y. The difference in age between these two localities and LZ-45 clearly supports the interpretation of Fuster, Santin, and Sagredo (1968) that there is a significant hiatus within their Series I basalts. The great difference in age found here suggests that the pre-trachyte basalts should be clearly distinguished from the overlying Series I basalts. Driscoll, Hendry, and Tinkler (1965) have already suggested the existence of such differences.

We have investigated three distinct localities in the Farmara section. A series of samples from the eastern edge of the Punta Fariones escarpment has been studied. They represent three different flow units at the base of this escarpment. One unit has been analyzed in some detail (LZ-4). Replicate samples from two different sampling points give results whose reproducibility is rather poor. We attribute this to the alteration observed for these samples. An average age of 10 ± 2 m.y. is suggested for this horizon. A single determination of a sample (LZ-12) about 50 m above this horizon gives an age of 5.3 m.y. This is quite inconsistent with other ages in this section. We infer that there has been significant argon loss from this sample. A single sample from the highest elevation in this section (sample LZ-3) gives an age of

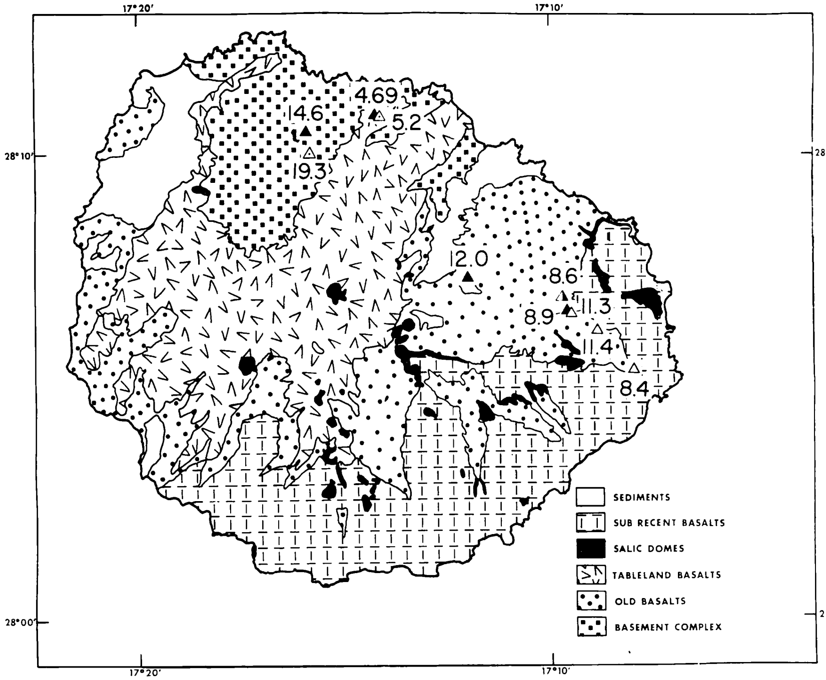

Fig. 5B. K-Ar ages of sampled units on La Gomera, in millions of years (table 2). Geology after Bravo (1964a). See captions to figures 2B and 4B for additional explanations.

5.8 m.y. A third sample (LZ-14), stratigraphically intermediate between the LZ-12 and LZ-3 localities, gives an age of 7.0 m.y. In summary, the age measurements suggest that the 500 m pile of basalts on the northern part of the island were extruded between 12 and 6 m.y. ago. Many additional measurements are necessary in order to determine the stratigraphic details within this section. Rothe (1964, 1966) studied the macro- and micro-fauna of a calcarenite deposit interbedded with the basalt flows near the base of the coastal Farmara section. He suggested a Middle Tortonian age for this deposit based on the presence of *Globigerina opertura* Cushman. According to Berggren (1969) the Middle Tortonian is between 10 and 9 m.y. ago. Therefore the K–Ar age of 12 to 6 m.y. ago suggested for the Farmara section is in good agreement with Rothe's assignment. The present data suggest that the Los Ajaches or Southern exposure of old basalts correlates with the upper portion of the Farmara section.

Two younger basalts from Lanzarote have been investigated. The first (LZ-42) sample from Playa Bastian, classified as Series III by Fuster, Santin, and Sagredo (1968), gives an age of 0.96 m.y. A second sample from just south of Tiagua, which is probably a Series III flow from Montaña Tamia to the north, yields an age of 0.034 ± 0.03 m.y.

TABLE 2

K–Ar ages of volcanic rocks from the Canary Islands

Diagram no.	Original field no.	Rock type	%K	Ar*/gm $\times 10^{-6}$ Scc	Ar^*/Ar_t	Age (m.y.)
		Lanzarote				
Pre-series I Basalts						
45	LZ-106	Trachybasalt	0.71	0.547	0.54	
				0.530	0.25	
				Avg. 0.539		19.00 ± 0.68
Basaltic Series I						
4	LZ-3	Picritic basalt	0.64*	0.298	0.24	
				0.274	0.19	
				0.242	0.18	
				Avg. 0.271		10.60 ± 1.12
4	LZ-104	Olivine basalt	0.62	0.261	0.25	
				0.215	0.38	
				0.195	0.21	
				Avg. 0.227		9.25 ± 0.57
44	LZ-105	Basanite	0.70*	0.225	0.21	
				0.205	0.29	
				Avg. 0.215		7.68 ± 0.53
14	LZ-102	Augite olivine basalt	0.79	0.223	0.34	7.00 ± 0.34
48	LZ-109	Plagioclase basalt	1.24	0.315	0.68	6.37 ± 0.13
5	LZ-103	Alkali olivine basalt	0.36	0.085	0.08	6.00 ± 0.15
3	LZ-101	Olivine augite basalt		0.163	0.21	
				0.133	0.34	
				Avg. 0.149		5.82 ± 0.36
12	LZ-11	Olivine–augite basalt	0.69	0.146	0.41	5.30 ± 0.19
Basaltic Series II, III, and IV						
42	LZ-110	Alkali olivine basalt	0.86	0.032	0.14	0.96 ± 0.10
41	LZ-112	Alkali olivine basalt	0.74	0.0001	0.006	0.034 ± 0.03
		Fuerteventura				
Basement Complex and Submarine Volcanics						
14	FV-19	Metavolcanic	1.34	1.900	0.51	35.30 ± 0.92
11	FV-14	Alkali syenite with aegirine augite	0.081	0.118	0.17	38.6 ± 3.75
12	FV-16	Hornblende–gabbro				
		Hornblende	0.67	0.558	0.56	20.80 ± 0.52
		Biotite	2.54	1.869	0.78	18.40 ± 0.32
Basaltic Series IVa						
20	FV-23	Plagioclase basalt	1.12	0.923	0.39	20.60 ± 0.94
Basaltic Series I						
4	FV-2	Augite basalt	1.11	0.735	0.40	16.55 ± 0.61
2	FV-4	Augite basalt	0.93	0.594	0.17	
				0.621	0.15	
				0.553	0.19	
				Avg. 0.589		15.88 ± 1.68
1	FV-5	Augite basalt	0.48	0.276	0.39	14.30 ± 0.52
23	FV-30	Amygdaloidal–olivine basalt	1.11	0.485	0.47	11.80 ± 0.33
Shield Volcanoes						
13	FV-18	Olivine basalt	1.07	0.181	0.20	4.25 ± 0.44
18	FV-24	Olivine basalt	1.11	0.081	0.14	1.83 ± 0.24
		Gran Canaria				
Basaltic Series I—(Tableland series, old basalts)						
52	CL-26	Plagioclase basalt	1.23*	0.820	0.80	15.00 ± 0.20
22	CL-11	Plagioclase basalt	0.96*	0.594	0.68	15.40 ± 0.26
1	GCU-14	Plagioclase basalt	1.40*	0.879	0.76	15.70 ± 0.27
		Plagioclase separate	0.35	0.226	0.53	16.12 ± 0.40
64	GCU-10	Olivine basalt	0.83*	0.338	0.25	10.20 ± 0.68
63	GCU-11	Plagioclase basalt	0.77*	0.355	0.67	11.50 ± 0.19

TABLE 2 (continued)

Diagram no.	Original field no.	Rock type	%K	Ar*/gm × 10^{-6} Scc	Ar*/Ar_t	Age (m.y.)
Ignimbritic-Trachytic Complex						
4	GCU-15	Trachyrhyolite	2.96*	1.885	0.42	15.00 ± 0.38
			2.99	1.802	0.70	
52A	GC-95	Rhyolitic tuff	3.28	1.528	0.46	
				1.669	0.85	
				Avg. 1.599	0.65	12.20 ± 0.22
42	GC-43	Soda Rhyolite	3.81	1.922	0.91	
				2.054	0.92	
				1.817	0.87	
				Avg. 1.931		12.65 ± 0.11
48	GC-90	Separated feldspars	3.67	1.913	0.52	13.10 ± 0.34
3	GCU-6	Separated feldspars	1.86	0.971	0.38	13.10 ± 0.50
45	GCU-32	Separated feldspars	2.40	1.276	0.66	13.30 ± 0.23
Phonolite Formation						
33	GC-64	Phonolite	4.55*	1.373	0.90	9.60 ± 0.11
33	GCU-35	Nepheline–phonolite	4.68*	1.841	0.94	9.80 ± 0.11
44	GC-53	Phonolite	4.30*	1.771	0.83	10.30 ± 0.13
47	GC-63	Phonolite	4.28*	1.771	0.56	
				1.728	0.64	
				2.051	0.80	
				Avg. 1.850	0.60	10.90 ± 0.22
46	GC-89	Nepheline–phonolite	4.10	1.740	0.61	10.60 ± 0.20
Roque Nublo Formation						
25	GC-105	Hauyne–tephrite	2.95	0.442	0.45	3.75 ± 0.12
41	GCU-29A	Tephrite	2.98*	1.451	0.77	
				0.380	0.28	
				Avg. 0.415		3.50 ± 0.09
Basaltic Series II: Post-Miocene basalts						
37	GCU-23A	Olivine basalt	0.47*	0.037	0.31	1.96 ± 0.10
39	GCU-25	Olivine basalt	0.80	0.066	0.12	2.05 ± 0.32
35	GCU-20	Olivine basalt	1.08*	0.095	0.34	2.20 ± 0.11
34	GCU-21	Olivine basalt	0.72*	0.088	0.49	
				0.074	0.40	
				Avg. 0.080	0.45	2.80 ± 0.08
			La Gomera			
Basement Complex Intrusives						
2A	20-359	Hornblende from Hornblende syenite	0.20	0.55	0.26	19.30 ± 1.58
2	LG-55	Hornblende	0.76	0.434	0.36	14.60 ± 0.67
Old Basalts						
9	G-1	Plagioclase basalt	0.74	0.352	0.44	12.00 ± 0.39
26	G-17	Olivine basalt	0.75	0.342	0.23	11.40 ± 0.80
23	G-14	Olivine basalt	0.71	0.318	0.27	11.25 ± 0.70
22	G-13	Plagioclase basalt	1.86	0.625	0.89	8.86 ± 0.13
17	G-8	Plagioclase basalt	1.25	0.429	0.69	8.64 ± 0.14
27	G-18	Olivine basalt	0.92	0.309	0.42	8.42 ± 0.29
Horizontal Basalts						
4A	LG-59	Olivine basalt	0.92	0.191	0.05	5.23 ± 2.13
4	LG-58	Olivine basalt	1.11	0.228	0.73	
				0.190	0.33	
				Avg. 0.209		4.69 ± 0.12

The decay constants used in the age calculations are:

$\lambda_\beta = 4.72 \times 10^{-1}$ yr.$^{-1}$; $\lambda_e = 0.584 \times 10^{-10}$ yr^{-1}

$\lambda_e/\lambda_\beta = 0.123$; Ar* = radiogenic argon

$K^{40}/K = 0.0119$ atomic %; Ar_t = total argon

* Potassium determined by isotope dilution technique.

For locations, see figures 2 to 5 and appendix. For stratigraphic subtitles and experimental method details, see text.

TABLE 3
Paleomagnetic results (by island, in order of decreasing age)

Diagram no.	Original field no.	N	D°	I°	J	R	K	θ′	φ′	Polarity	Age, m.y.
Lanzarote											
45	LZ106	8	10.9	+46.3	0.827	7.683	22.1	+80.4	+85.5	N*	19.00 ± 0.68
4	LZ104	6	352.5	+23.8	0.793	5.981	269.9	+72.1	194.3	N	(9.25) ± 0.57
44	LZ105	8	274.6	+79.0	0.583	7.325	10.4	+28.5	325.8	I*	7.68 ± 0.53
14	LZ102	6	54.4	+09.2	1.837	5.721	118.0	+33.2	94.6	N*	7.00 ± 0.34
48	LZ109	4	190.1	—44.9	3.018	3.984	183.3	—80.7	273.5	R	6.37 ± 0.13
5	LZ103	4	28.7	+51.5	1.747	3.929	42.5	+65.2	65.2	N	6.00 ± 0.15
3	LZ101	5	205.6	—27.7	4.242	4.987	307.7	—62.4	285.7	R	5.82 ± 0.36
12	LZ11	2	25.8	+38.5	0.304	1.978	—	+65.6	88.5	N	5.30 ± 0.19
42	LZ110	6	32.0	+39.0	2.468	5.980	247.2	—60.4	86.2	N	0.96 ± 0.10
41	LZ112	7	8.2	+45.9	6.760	6.988	506.8	+82.6	91.1	N†	0.034 ± 0.03
Fuerteventura											
14	FV19	2	206.5	+25.5	0.042	1.989	—	—41.0	314.5	R	35.30 ± 0.92
11	FV14	4	218.1	+19.4	0.015	3.616	7.8	—36.8	300.2	R*	38.60 ± 3.75
12	FV16	4	142.6	—03.4	0.016	3.710	10.3	—45.5	49.5	R*	20.80 ± 0.52 18.40 ± 0.32
20	FV23	6	184.1	—65.1	0.712	5.986	48.1	—71.0	178.2	R	20.60 ± 0.94
4	FV2	4	18.1	+47.8	0.270	3.946	55.1	+74.1	73.6	N	16.55 ± 0.61
2	FV4	5	96.8	+66.5	0.101	4.858	28.2	+16.9	32.5	I	15.88 ± 1.68
1	FV5	3	00.8	+27.5	0.288	2.765	8.5	+76.6	166.5	N*	14.30 ± 0.52
23	FV30	4	190.0	—33.4	0.810	3.959	73.8	—76.3	305.4	R	11.80 ± 0.33
13	FV18	6	148.4	—54.0	2.392	5.963	134.1	—62.5	100.4	R	4.25 ± 0.44
18	FV24	6	188.9	—31.8	2.931	5.977	220.8	—76.1	311.4	R†	1.83 ± 0.24
Gran Canaria											
1	GCU14	2	315.8	+53.7	0.089	1.945	—	+52.0	278.8	N	16.12 ± 0.40 15.70 ± 0.27
4	GCU15	3	355.2	+49.5	7.050	2.924	26.3	+85.2	288.1	N	(15.0) ± 0.38
22	CL11	4	20.4	+47.1	5.064	3.924	39.6	+72.0	72.4	N	15.4 ± 0.26
52	CL26	4	9.2	+41.1	1.672	3.870	23.2	+80.6	104.2	N*	15.0 ± 0.20
45	GCU32	3	18.2	+36.3	0.177	2.992	248.3	+71.7	99.4	N	13.3 ± 0.23
3	GCU6	2	6.8	+51.3	2.229	2.000	—	+82.9	42.6	N	13.10 ± 0.50
48	GC90	4	185.5	—40.0	0.148	3.975	119.5	—82.6	301.6	R	13.10 ± 0.34
42	GC43	4	6.7	—53.6	0.255	3.761	12.6	+27.5	116.8	I*	12.65 ± 0.11
63	GCU11	2	172.8	—40.4	1.553	1.989	—	—81.9	42.5	R	11.5 ± 0.19
47	GC63	3	24.3	+65.8	0.043	2.988	111.9	+62.5	24.6	N	10.9 ± 0.22
44	GC53	3	191.7	—37.6	0.004	2.974	75.7	—77.3	288.7	R	10.3 ± 0.13
64	GCU10	2	218.9	—42.6	2.244	1.998	—	—55.1	254.3	R	10.2 ± 0.68
33	GC64	3	94.0	+52.5	66.910	2.929	28.0	+11.8	46.7	I	9.70 ± 0.11
25	GC105	3	29.0	—14.1	0.078	2.311	2.9	+55.6	109.8	N	3.75 ± 0.12
41	GCU29A	3	172.7	—04.7	0.410	2.922	25.6	—63.3	4.5	R	3.50 ± 0.09
34	GCU21	7	185.5	—12.9	0.074	5.624	4.4	—67.9	333.4	R*	2.80 ± 0.08
35	GCU20	7	195.8	—30.7	1.142	6.953	129.0	—71.4	292.9	R	2.20 ± 0.11
39	GCU25	3	191.2	—29.5	3.106	2.926	27.1	—74.0	305.4	R	2.05 ± 0.32
37	GCU23A	7	172.4	—57.7	0.734	6.913	69.1	—77.9	138.6	R	1.98 ± 0.10
La Gomera											
2	LG55	4	357.9	—08.4		2.826	2.6	+57.5	166.6	N*	14.60 ± 0.67
9	G1	2	322.9	+30.6		1.778	—	+53.9	241.9	N	12.00 ± 0.39
26	G17	2	204.0	+04.6		1.953	—	—51.8	301.7	R	11.40 ± 0.80
23	G14	2	196.5	—23.3		1.999	—	—67.8	295.6	R	11.25 ± 0.70
22	G13	2	348.4	+33.4		1.993	—	+75.4	212.1	N	8.86 ± 0.13
17	G8	2	244.6	+68.6		1.999	—	+08.0	308.4	I	8.64 ± 0.14
27	G18	2	180.9	—39.9		1.997	—	—84.5	334.4	R	8.42 ± 0.29
4	LG58	6	15.0	+34.2		5.993	736.5	—73.4	104.0	N	4.69 ± 0.12

Fuerteventura (fig. 3)

Fuerteventura is structurally and lithologically the most varied of the Canary Islands. Both Fuerteventura and Lanzarote rest on a narrow platform and are separated by the shallow Strait of Bociana. Structurally, Fuerteventura probably consisted at one time of two islands, the Jandia Peninsula and the main island now joined by the Istmo de la Pared. The central western part of the main island is made up of a complex terrain of metavolcanics and metasediments and plutonic rocks ranging from pyroxenites to syenites. In the present survey we have studied samples from nine different localities.

The three localities from Jandia are from the upper 200 m of the north-facing escarpment where the main road crosses the peninsula. They are all olivine augite basalts with only minor amounts of alteration products present. The ages in stratigraphic sequences from old to young are 16.6 m.y., 15.9 m.y., and 14.3 m.y. The concurrence of absolute ages and stratigraphic sequence is reassuring. We cannot, however, claim that our experimental uncertainties would have allowed us to reconstruct this sequence from the ages alone. It seems quite clear that our Jandia section was erupted between 17 and 14 m.y. ago.

Three samples from the basement complex have been studied. The first (FV-14) is the low grade metavolcanic rock exposed in the base of the Molinas Valley. It yields an age of 35.3 m.y. Unfortunately, it is not possible to establish directly the relation of these metavolcanic rocks to the intrusive rocks exposed further south. It seems conceivable however that the rocks exposed here correlate with the older volcanic rocks that constitute the spilite complex of Hausen (1958) exposed to the south; the sample we have dated is a greenstone. Without a much more detailed study of this terrain we can only infer that the time of an extrusion of these rocks is in excess of 35 m.y.

The occurrence of hornblende and mica-bearing syenitic rocks in ringdike structures (Fuster and others, 1968a) of the basement complex

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Diagram number refers to figures 2, 3, 4, and 5. Original Field no.: LZ = Lanzarote; FV = Fuerteventura; CL, GC, and GCU = Gran Canaria; G and LG = La Gomera. N = number of separate samples from the given body. D and I = declination and inclination of remanent magnetism, in degrees east of geographic north, and with respect to horizontal (+ = downward; — = upward) respectively. J = intensity of magnetization in emu/gm × 10^{-3}. R = resultant vector length, applying unit vector per sample. K_{max} = precision parameter = N-1/N-R (Fisher, 1953). θ' and ϕ' = latitude and longitude of virtual geomagnetic pole (the surface expression of the geocentric axial dipole which will create the observed D and I): latitude is positive for northern hemisphere; negative for southern hemisphere; longitude is in degrees east. Polarity is N (normal), R (reversed), and I (intermediate, or equatorward or the 30° lat). D, I, J, R, k_{max}, θ', and ϕ' are all based on the remanent magnetism direction after treatment in three alternating magnetic field values (100, 200, and 300 oersteds) and computation for maximum K, using one demagnetized D and I result per sample (Watkins and Richardson, 1968). Age from table 2.

† These polarity:age data cannot be applied to definition of the polarity time scale, because the K:Ar data do not satisfy the criteria of Cox and Dalrymple (1967).

* These polarity:age data cannot be applied to definition of the polarity time scale, because of an insufficiently well defined direction of remanent magnetism ($K_{max}<25$), according to the criterion of McDougall and Chamaulaun (1966).

provides an unusual opportunity to date these coarse-grained rocks. Krummnacher (personal commun., 1970) has shown that deep-seated or plutonic rocks associated with volcanoes may retain unusual amounts of initial argon, capable of producing apparent K–Ar ages in excess of 200 m.y. in Tertiary rocks. Considerable caution is thus required in interpreting ages from a single phase or whole rocks crystallizing under such deep-seated conditions. We have separated both hornblende and biotite from a single hand specimen of basic syenite (FV-12) which outcrops west of Vega. The ages of these two minerals are almost in agreement, hornblende giving an age of 20.8 m.y. and biotite of 18.4 m.y. An aegirine–augite separated from an alkali syenite located north of Morro Fenduca (FV-11) gives a calculated age of 38.60 m.y. These data at least show that the Mesozoic sediments exposed in the west-central coast of Fuerteventura are unlikely to be younger than the intrusive complex.

The older basalt (Series IVa, fig. 3B) which outcrops along the northwestern shore near Toston Cotillo (FV-20) was sampled near its northernmost exposure. A single sample yields an age of 20.6 m.y., very similar to the age found by Rona and Norwalk (1970) for highly fractured basaltic lavas intruded by dikes on the coast at Barranco de Los Molinos northwest of sites FV 13 and 14 (fig. 3A) and to results from across the Strait of Bocaina for the southernmost rocks of Lanzarote, (LZ-45). The rocks along the northwestern shore of Fuerteventura also show extensive evidence of cataclastic deformation. We tentatively suggest that the 20 m.y. old rocks on Lanzarote and Fuerteventura are correlative and furthermore that the intrusive ringdikes on Fuerteventura correlate in age with these older basalts.

We have dated one sample (FV-23) from the Series I basalts in east-central Fuerteventura. This sample, from an escarpment west of Puerto del Rosario, provides K–Ar age of 11.8 m.y.

It is clear from our limited data that the subdivision of the Series I rocks on Fuerteventura must be much more complex than suggested by most geologic studies (Hausen, 1958; Fuster and others, 1968a). We suggest that the Jandia basalts should be clearly distinguished from other basalt series from Fuerteventura. The single K–Ar age determined for the Series I Middle basalts suggests that this series may overlap in time with the basalts of the Farmara complex of Lanzarote.

Samples from two of the younger shield volcanoes on Fuerteventura, FV-13 and FV-18, have been dated. The data show these are very much younger materials. They give ages of 4.2 and 1.8 m.y. respectively. The differences between these two samples suggest that the shield volcanoes were erupted over a rather long period of time.

Gran Canaria (fig. 4)

We have dated more units on Gran Canaria than on any of the other three islands studied. Because of the finer stratigraphic control available (table 1), we present the results in order of the stratigraphic subdivisions of Fuster and others (1968b).

1. *Basaltic Series I.*—These rocks are abundantly exposed along the western and southwestern edge of the island (fig. 4B). They consist of horizontal to subhorizontal basalt flows from 1 to 4 m thick. Fuster and others (1968b) and Schmincke (1968) note single sections that are up to 1000 m thick. The structural relations of the overlying salic rocks and the older basalts have been studied by Schmincke (1968).

Schmincke (1968) has presented very convincing evidence that the older basalt series of Hausen (1962) and Fuster and others (1968b) is divided by an unconformity along the southwestern sea coast. The lower part of this section contains many more dikes than the upper part and appears to be extensively altered. Hausen, Schmincke, and the Fuster group also had subdivided the older basalts into two petrological groups, the upper group consisting of plagioclase-rich basalts and the lower group consisting of olivine–augite basalts. Schmincke (1968, 1969) divides the unit into a lower olivine plus clinopyroxene phyric group overlain by plagioclase-rich pahoehoe basalts, in turn overlain by 50 to locally 300 m of aphyric trachybasalts. Recent geological investigations support the hypothesis that the old basalts were extruded as part of a large composite shield volcano (Schmincke, 1967, 1968).

Samples from six different localities in the older basalt horizon have been investigated (figs. 4A and 4B). All these samples (GC-1, -4, -22, -52, -63, and -64) are basalt or trachybasaltic with plagioclase and augite more abundant than olivine. Samples from four of the six basalt localities give ages that range between 15 and 16 m.y. A plagioclase separate from GC-1 gives an age of 15.7 m.y. The excellent agreement of these different samples clearly establishes the age of the plagioclase basalts that underlie the rhyolite–ignimbrite sequence (within the trachyte–syenite complex of fig. 4B) in the western part of the island. Two samples (GC-64 and GC-63) from just above the village of Tasartico, however, give ages of 10.2 and 11.5 m.y. respectively. These two samples were collected about 300 m apart. We have no reason to question the accuracy of these results. We suggest that these rocks are conceivably associated with younger intra-valley basalt flows similar to those noted by Schmincke (1968) or may conceivably be sills.

The limited sampling of this section does not allow any estimate of the time represented by this older basalt section. The samples analyzed here are probably above the disconformity noted by Schmincke (1968). It is thus quite possible that volcanic activity on the island can be extended back to at least 17 to 18 m.y. ago.

2. *Syenitic–Trachytic Complex.*—Most of the western half of this island is covered by a series of rhyolitic and trachytic ignimbrites and lava flows (fig. 4B). These rocks have a wide range of both textures and compositions (Schmincke and Swanson, 1967). Rhyolitic ignimbrites are common in both the extra and intra-caldera types. Massive phonolite flows are largely restricted to the upper part of this section in the central and southern part of the island. Hausen (1962) and Fuster and others (1968b) originally subdivided these rocks into two stratigraphic

units: rhyolitic rocks and phonolites. In much more detailed studies Schmincke (1967, 1968, 1969) has been able to subdivide and correlate the salic rocks in very fine detail. He established several chemically distinct types of rhyolites and a sharp transition from the rhyolites to the trachyphonolites via trachytes.

GC-3 and GC-4 are from the basal section described by Schmincke (1968). GC-3 is from the basalt composite ignimbrite, whereas GC-4 is a trachyrhyolitic lava flow from immediately above the basal ignimbrite. The K–Ar ages determined for these rocks (13.1 and 15.0 m.y. respectively) are inconsistent with the stratigraphic relations, although at the 95 percent confidence level the difference is very small. Duplicate measurements of both K and Ar contents on sample GC-4 are nevertheless in good agreement. Assuming Schmincke's stratigraphy to be correct the most reasonable interpretation of the observations is that some loss of argon has taken place in the anorthoclase of GC-3. If this is the correct explanation, it might be argued that the ages of the tuffaceous rhyolites and rocks (GC-48, $t = 13.1$ m.y.; GC-42, $t = 12.7$ m.y.; the rhyolite inlier GC-45, $t = 13.3$ m.y.; and GC-52A, $t = 12.2$ m.y.) may also be somewhat too young. Such a widespread systematic argon loss would not be likely in our opinion, but we are unable to say with assurance that the apparent time difference between most of the rhyolites ages and the older basalts is significant. The older basalts and rhyolite most likely overlap in time: the similar age of GC-4 and GC-3 at least indicates that no definite large time interval exists between the extrusion of the older basalts and the oldest rhyolites, in agreement with the geological observations (Schmincke, 1967).

3. *The Phonolite Series.*—Massive green trachyphonolitic flows cover areas in the south-central part of the island (fig. 4B). Petrographically similar flows are found along the northeastern shorelines. The outcrops in the area south of Las Palmas are of interest because they occur at the base of the section that includes a fossiliferous limestone. This limestone has generally been accepted as Vindobodian or Middle Miocene (Rothpletz and Simonelli, 1890). We have dated five different samples from the Phonolite Series. Three of these are from the Fataga valley, north from Maspalomas. A phonolite from the Fataga region gives an age of 10.3 m.y. Two samples from the southern extremity of the Fataga valley (GC-46 and GC-47) give very similar ages of 10.6 and 10.9 m.y. Two samples from a large phonolite exposure south of Las Palmas (GC-33) provide identical ages close to 9.7 m.y.

The complete lack of overlap between ages from the rhyolites and phonolites and the consistency of ages within each group show that the phonolites are a younger series than the rhyolites, extruded 2 to 3 m.y. after the formation of the rhyolites. This conclusion may be modified to some extent if lower parts of the phonolite section prove to be older.

Fuster and others (1968b) have interpreted our K–Ar data as conflicting with the paleontological assignment of the overlapping limestones. We believe that this inconsistency is not real. First, we suggest that the paleontological assignment lacks precision. This was clearly recognized in the original work of Rothpletz and Simonelli (1890), who concluded: "The majority of the fossil types go without any changes from the Helvetian to the Pliocene and some go down to the Aquitanian or even the Tongrian; others have survived to the present. If we disregard the new and uncertain fossil types which are not included in the table, there is a little surplus of those fossil types which only go up to the Helvetian compared to those which go down only to the Pliocene or Tortonian. But the difference is too small to put our beds in the Helvetian." Secondly, recent studies have shown that the "accepted" age of 12 to 13 m.y. for the Miocene-Pliocene boundary (Kulp, 1961; Holmes, 1959) is probably incorrect. Dymond (1966) has determined K–Ar ages on a series of ash layers from a deep sea core associated with fossil bearing sediments. He suggests that the age of the Miocene-Pliocene boundary is 4.5 to 5 m.y. Berggren (1969) and Hays (personal commun., 1970) have suggested a similar time for this boundary based on the correlation of faunal zones and paleomagnetic stratigraphy in several deep-sea cores. With this upward extension of the Miocene, the relationship of our age determinations and the observed fossil horizons are quite complimentary. The age determinations reported here indicate that the limestone carrying the fossils is younger than 9.0 m.y. Using the inverse of the argument used by Fuster and others (1968b) we suggest that our results place an upper limit on the absolute age of this paleontological horizon.

4. *The Roque Nublo Series.*—The materials overlying the phonolite flows contrast with other rocks on the island. They consist of a series of "nuee ardente" agglomerates and breccias, intercalated with basaltic and tephritic flows. The upper part of this series contains an unusual horizon which has been designated the Roque Nublo Formation. It consists of extensive sheets of rather massive but unsorted pyroclastic material. The exact origin of this unit is not well understood. Many beds contain casts of trees and other plant remains, which Schmincke (1968) tentatively suggests may establish a Pliocene age for the unit.

We have dated two samples from flows within the upper portion of this series. One of these (GC-25) is from the central part of the island east of Tejeda and the second (GC-41) from the east side of Barranco Tirajana. The two samples yield very similar ages (3.75 m.y. and 3.50 m.y. respectively). Using the Miocene-Pliocene boundary suggested by Dymond (ms) and Berggren (1969), these ages support the suggestion of Schmincke (1968), assigning the unit to the Pliocene on paleontological grounds.

5. *The Post-Miocene Basaltic Series.*—One of the most extensive stratigraphic units on the island is a series of young basalts that cover most of the northeastern half of the island (Series II, fig. 4B). A sequence of these flows more than 500 m thick exposed in Berranco Guagedeque west of Aguimes does not expose the lower contact. We have dated four samples from this vicinity, three from the region just north of Barranco Guagadeque (GC-34, -35, -37) and one from the mouth of Barranco

Guagadeque (GC-39). The ages range from 2.8 to 2.0 m.y. The age determinations clearly establish the Upper Pliocene age of this series. The extrusion of this series of basalts apparently began very shortly after the formation of the Roque Nublo Formation.

La Gomera (fig. 5)

The geology of this island appears to be relatively simple (Gagel, 1925). The series of plutonic rocks exposed in the deep canyons of the northwestern part of the island (Cendero, 1967) are overlain by a series of titled basalts which are well exposed in the long canyon northwest from the coast of San Sebastian. Both of these series are unconformably overlain by a series of nearly horizontal basalts (Bravo, 1964a, 1964b). Samples from ten localities have been studied.

We have dated two samples from the basement complex (LG-2 and -2A): both are separated hornblende samples. From these two La Gomera rocks we infer a minimum age for the basement of about 15.0 m.y.

Six samples from the older basalts in the Canyon northwest of San Sebastian fall into two age groups 12.0 to 11.2 m.y. (LG-9, -23, and -26) and 8.8 to 8.4 m.y. (LG-17, -22, and -27). We have no evidence for an unconformity separating these two groups and do not know the detailed stratigraphic relationships, but the age determinations clearly suggest that there may be a hiatus within this series.

The horizontal (Tableland) basalts that overlie the tilted older basalt series in some places directly overlie the basement rocks (fig. 5B). Two samples from this series (LG-4 and -4A) provide ages 5.2 and 4.7 m.y. The structural unconformities between these horizontal basalts, the tilted older basalts, and the basement rocks suggest that some uplift and tilting of the island occurred between 8 and 5 m.y. ago (in the uppermost Miocene). Hausen (1965) suggested that the uplift along the northern shores of the island is of the order of a thousand meters.

SUMMARY OF VOLCANIC STRATIGRAPHY

A compilation of our age determinations is shown in figure 6 as a function of the previously determined volcanic stratigraphy. The most significant correlation appears to be the similarity in age of the Jandia section of Fuerteventura and the older basalts of Gran Canaria. Contrary to previous suggestions (Blumenthal, 1961; Hausen, 1962), the extensive Tableland or Series I Basalts on Lanzarote, La Gomera, and probably Fuerteventura do not appear to have an exact time counterpart on Gran Canaria.

When viewed against a linear time scale, it is clear that the volcanic history of Gran Canaria can be divided into two major periods: first, the lavas of the older shield volcano capped by, and gradational into, a series of rhyolitic-trachytic ignimbrites and phonolite flows; second, a much younger period consisting of a cover of explosive volcanics and basalts. These two are separated by a major erosional unconformity and locally by a series of carbonate-rich and detrital sediments. The absolute ages establish that there is a break of at least 5 m.y. between the time

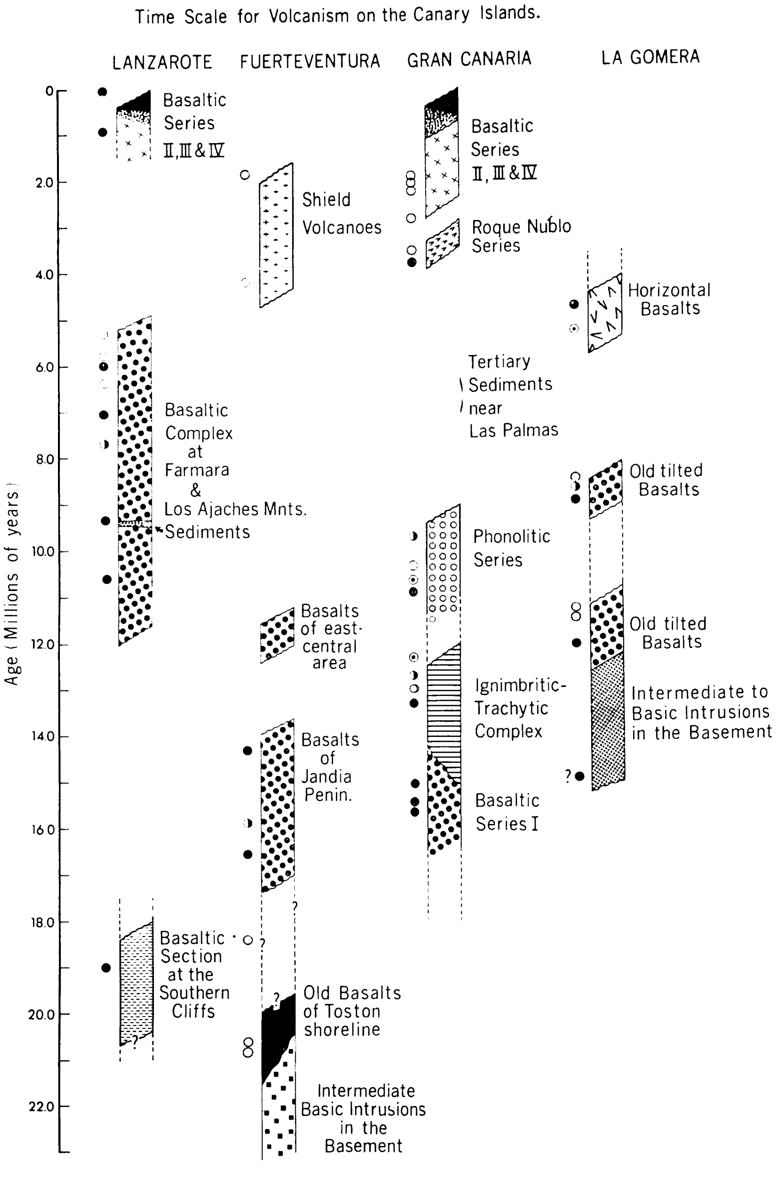


Fig. 6. Summary time scale for volcanism on Lanzarote, Fuerteventura, Gran Canaria, and La Gomera. K:Ar age determinations (table 2) shown as circles. Polarities of units also indicated by circles: open = reversed polarity; full = normal polarity; split = transitional (see caption to fig. 2A for explanation); central dot = unoriented (no polarity determination). Stratigraphic terminology after Fuster, Santin, and Sagredo (1968), Fuster and others (1968a, 1968b), and Bravo (1964a). For geographic terms see figures 2A, 3A, and 4A.

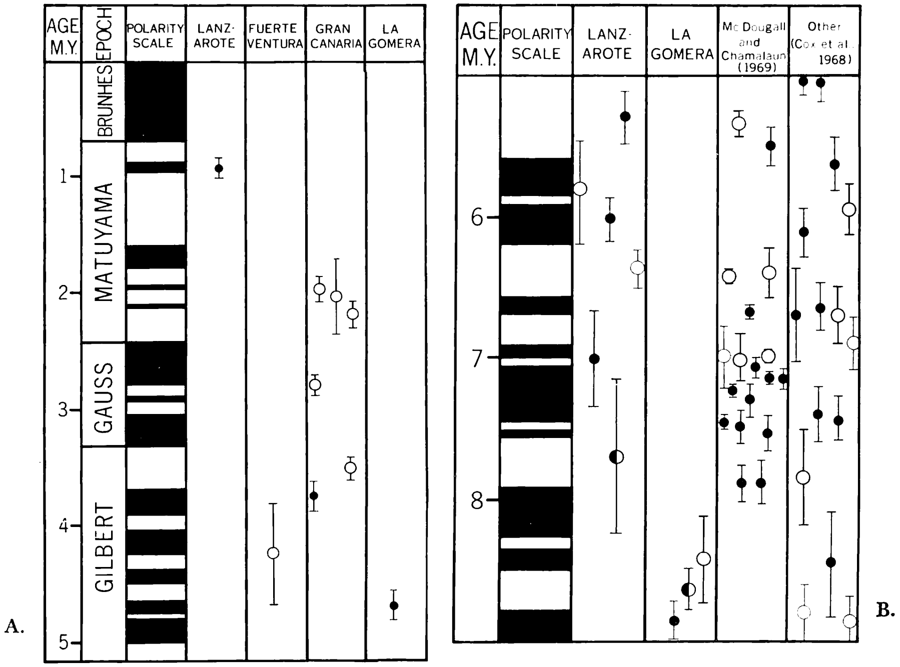


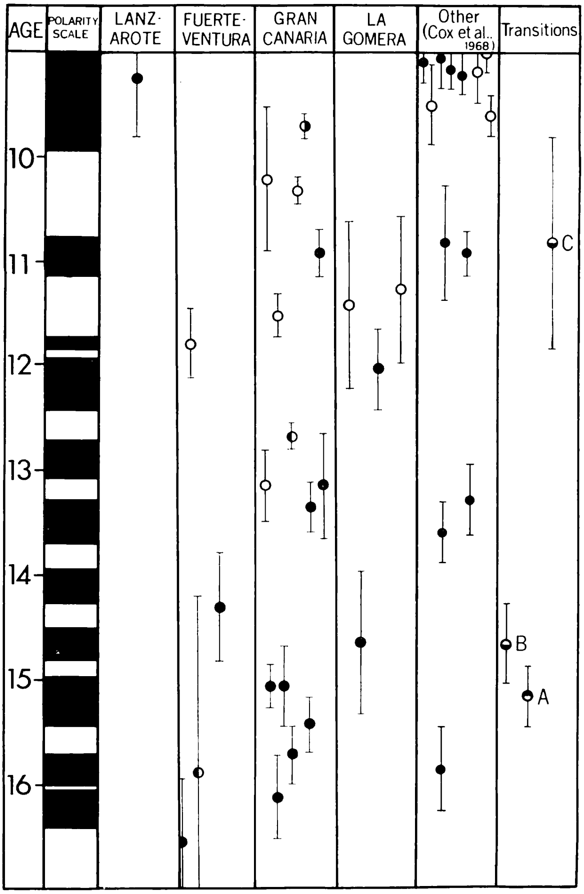
Fig. 7. Comparison of K:Ar and magnetic polarities, with the established and predicted geomagnetic polarity scales. Open circles = reversed polarity; full circles = normal polarity; split circles = transitional polarity (see caption fig. 2A for explanation). Error limits of the K:Ar age, included (see text for method of computation). See tables 2 and 3 for detailed results.

A. Results for period 0 to 5 m.y. Polarity scale is after Cox (1969) for 0 to 4.2 m.y. and Heirtzler and others (1968) for older parts. Black = normal polarity; clear = reversed polarity. Note that the polarity scale between 4.2 and 5.1 m.y. is not yet agreed upon and may be subject to substantial revision as the associated research continues.

B. Results for period 5 to 9 m.y. Polarity scale is after Heirtzler and others (1968). Additional results by McDougall and Chamalaun (1969) for Indian Ocean islands added, and summary of other results by Cox and others (1968) also shown.

of eruption of the massive phonolites and the onset of the final stages of the Roche Nublo volcanics which are nuee ardente materials and tephrite flows. The relations of the different units within the older and younger volcanic periods on Gran Canaria are not clearly established by our data. Some general conclusions are nevertheless possible: the ages of the rhyolites and phonolites indicate that a long period of salic volcanism followed the buildup of the shield volcano, and there is some evidence that this period of volcanic-activity may have been interrupted by a period of 1 to 2 m.y.

The younger volcanic period on Gran Canaria includes a very rapid change in the character of eruptions from nuee ardente type material interspersed with highly alkaline flows and plugs to nephelinites and normal olivine basalts. The age determinations suggest that the character of volcanism changed in a very short time interval, perhaps only a few hundred thousand years.



C. Results, for period 9 to 17 m.y. Polarity scale as in (B). Also included are independent results summarized by Cox and others (1968) and three examples of the K:Ar ages of rocks extruded during a transitional between polarities: A = Steens Mountain reversed to normal polarity change (Baksi and others, 1967); B = Picture Gorge normal to reversed polarity change (Watkins and others, 1968); C = the W36 normal to reversed polarity change of Dalrymple and others (1967).

The existence of an older basaltic series on Lanzarote and Fuerteventura raises the interesting possibility: might the rocks below the disconformity described by Schmincke (1968) along the southwest coast of Gran Canaria correspond to the older basalt series on these islands?

THE POLARITY TIME SCALE

The paleomagnetic data for each dated unit are given in table 3 and included diagrammatically in figures 2 to 6. In figure 7, we present the magnetic polarities, K–Ar ages (with error limits), and the independently defined polarity scale, which is relevant to global correlation of volcanic activity, since polarity changes are world-wide synchronous events. The data are presented in three groups for clarity: figure 7A shows the data for the period 0 to 5 m.y. The independent polarity scale is after Cox (1969) except for the period 4.50 to 5.0 m.y., which is predicted by Heirtzler and others (1968). The predicted polarity time scale is also used for figures 7B and 7C, which are for data in the intervals 5 to 9 m.y. and 9 to 17 m.y. respectively. Available independent results are added to figures 7B and 7C. No data are given for Fuerteventura or Gran Canaria in the interval 5 to 9 m.y., since no units were dated in this interval.

Within experimental precision the data in figure 7A agree with the polarity-time scale for the last 5 m.y. The Jaramillo normal event ($t = 0.85$ to 1.0 m.y.) is clearly detected on Lanzarote, the Matuyama reversed epoch is recorded by three Gran Canaria bodies. The thick lava sequences in the deeply incised valley of eastern Gran Canaria are capable of providing data very amenable to fine definition of the lower Matuyama epoch. One of the reversed events within the Gauss normal epoch is detected on Gran Canaria.

The remainder of the data (fig. 7A and 7C) cannot be used to test the validity of the predicted polarity scale because of the inherently limited precision of the K:Ar method when compared to the character of the predicted polarity scale (Cox and Dalrymple, 1967). The data at this time can only be added to the limited results which eventually may more finely delineate the polarity time scale, particularly for the period between 0 to 7 m.y., but they also obviously serve to define local age:polarity mapping units, which can be readily extended during field mapping methods. (For a summary of the methods used to measure magnetic polarities of igneous rocks in the field, see Watkins, Richardson, and Mason, 1966b.) Only by the use of such mapping methods in sequences of extensive volcanism with some K–Ar age control established can finer definition of the geomagnetic polarity history be expected to materialize. Broad definition may result for older parts of the polarity scale: it appears that the first reversely magnetized lava with an age between 12 m.y. and 14.5 m.y. has been found on Gran Canaria (fig. 7C).

CONCLUSIONS

It is evident that previous between-island correlations and stratigraphic age assignments such as those by Blumenthal (1961), Hausen (1962), and Rothe (1966), which were based on petrographic similarities and structural positions, are greatly oversimplified. In particular, the correlation of the basalts of the Farmara section, Lanzarote ($t = 12$ to 6 m.y.), with the post-Miocene basalts of Gran Canaria ($t = 3$ to 1.5 m.y.) by Rothe (1966) is clearly inaccurate. Geophysical data from the islands (McFarlane and Ridley, 1968, 1969; Dash and Bosshard, 1969) and from the facing continental shelf (Dillon personal commun. 1970), as well as our K–Ar data, suggest that the Canary Islands are separate volcanic edifices that evolved independently for at least the last 20 m.y. Fuerteventura clearly has the oldest outcrops, but it is essential that data from the islands of Tenerife, Hierro, and La Palma be presented before the suspected westward age decrease inherent in theories of regional genesis can be soundly evaluated. The ages of the islands are not greater than those inferred for the local basement by various geophysical methods and arguments (summary by Nafe and Drake, 1969).

The 20 m.y. period of volcanic activity observed in the Canary Islands stands in strong contrast to the very rapid evolution and relatively brief volcanic history observed in many purely oceanic islands, such as the Hawaiian Islands. It remains to be seen if the petrological and corresponding geochemical diversity within and between islands in this limited part of the crust of the oceanic and continental shelf can be explained as an essential function of the broad quantitative time scale which we have now defined.

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REFERENCES

Baker, I., Gale, N. H., and Simons, J., 1967, Geochronology of the St. Helena volcanoes: Nature, v. 215, p. 1451-1456.

Baksi, A. K., York, D., and Watkins, N. D., 1967, The age of the Steens Mountain geomagnetic polarity transiction: Jour. Geophys. Research, v. 72, p. 6299-6308.

Berggren, A., 1969, Rates of evolution in some Cenozoic plantonic foraminifera: Micropaleontology, v. 15, p. 351-365.

Blumenthal, M. M., 1961, Rasgos principales de la geologia de las Islas Canarias, con datos sobre Madeira: Inst. geol. min. Espãna Bol., v. 77, p. 1-130.

Bourcart, J., and Jeremine, E., 1937, Gran Canaria: Bull. volcanol., ser. 1, v. 2, p. 1-77.

Bravo, T., 1964a, Estudio geologico y petrographico de la isla de La Gomera, I: Inst. "Lucas Mallada", Estudios Geol., v. 20, p. 1-21.

———— 1964b, Estudio geologico y petrographico de la isla de La Gomera, II. Petrologia y quimismo de las rocas volcanicas: Inst. "Lucas Mallada", Estudios Geol., v. 20, p. 23-56.

Cendrero, A., 1967, Nota previa sobre la geologia del complejo basal de la Isla de La Gomera: Inst. "Lucas Mallada", Estudios Geol. v. 23, p. 71-79.

Chamalaun, F. H. and McDougall, J., 1966, Dating of geomagnetic polarity epochs in Reunion: Nature, v. 210, p. 1212-1214.

Cox, Allan, 1969, Geomagnetic reversals: Science, v. 163, p. 237-245.

Cox, Allan, and Dalrymple, G. B., 1966, Paleomagnetism and potassium-argon ages of some volcanic rocks from the Galapagos Islands: Nature, v. 209, p. 776-777.

———— 1967, Statistical analysis of geomagnetic reversal data and the precision of potassium-argon dating: Jour. Geophys. Research, v. 72, p. 2603-2616.

Cox, Allan, Doell, R. R., and Dalrymple, G. B., 1968, Radiometric time-scale for geomagnetic reversals: Geol. Soc. London Quart. Jour., v. 124, p. 53-66.

Cox, Allan, Hopkins, D. M., and Dalrymple, G. B., 1966, Geomagnetic polarity epochs, Pribilof Islands, Alaska: Geol. Soc. America Bull., v. 77, p. 883-910.

Dalrymple, G. B., and Cox, Allan, 1968, Paleomagnetism, potassium-argon ages and petrology of some volcanic rocks from Cocos Island: Nature, v. 217, p. 323-326.

Dalrymple, G. B., Cox, Allan, Doell, R. R., and Grommé, C. S., 1967, Pliocene geomagnetic polarity epochs: Earth Planetary Sci. Letters, v. 2, p. 163-173.

Dash, B. P., and Bosshard, E., 1969. Seismic and gravity investigations around the western Canary Islands: Earth Planetary Sci. Letters, v. 7, p. 169-177.

Dietz, R. S., and Sproll, W. P., 1970. East Canary Islands as a microcontinent within the Africa-North America continental drift fit: Nature, v. 226, p. 1043-1045.

Doell, R. R., Dalrymple, G. B., and Cox, Allan, 1966, Geomagnetic polarity epochs: Sierra Nevada data: 3: Jour. Geophys. Research, v. 71, p. 531-541.

Driscoll, E. M., Hendry, G. L., and Tinkler, K. J., 1965, The geology and geomorphology of Los Ajaches, Lanzarote: Geol. Jour., Liverpool, v. 4, p. 321-334.

Dymond, J. R., ms, 1966, Potassium-argon geochronology of deep-sea sedimentary materials: Ph.D. thesis, Univ. California, San Diego.

Fisher, R., 1953, Dispersion on a sphere: Royal Soc. London Proc., v. 217, p. 295-305.

Fritsch, K. von, 1867, Reisebilder von den Canarischen Inseln: Petermanns Geog. Mitt. (Gotha) Ergänzungsheft, v. 5(22), p. 1-44.

Fuster, J. M., Cendrero, A., Gastesi, P., Ibarrola, E., and Ruiz, J. L., 1968a, Geology and Volcanology of the Canary Islands, Fuerteventura: Inst. "Lucas Mallada", Madrid, Internat. Symposium Volcanology, Tenerife, Sept. 1968, Spec. Pub., 239 p.

Fuster, J. M., Hernandez-Pacheco, A., Munoz, M., Badiola, E. R., and Cacho, L. G., 1968b, Geology and Volcanology of the Canary Islands, Gran Canaria: Inst. "Lucas Mallada", Madrid, Internat. Symposium Volcanology, Tenerife, Sept. 1968, Spec. Pub., 243 p.

Fuster, J. M., Santin, S. F., and Sagredo, A., 1968, Geology and Volcanology of the Canary Islands, Lanzarote: Inst. "Lucas Mallada", Madrid, Internat. Symposium on Volcanology, Tenerife, Sept. 1968, Spec. Pub., 177 p.

Gagel, C., 1925, Begleiworte zu der Karte von La Gomera mit einem Anhang über die Caldera-frage: Deutsche geol. Gesell. Zeitschr., A, Abh., v. 77, p. 551-574.

Hausen, Hans, 1958, On the geology of Fuerteventura (Canary Islands): Soc. Sci. Fennicae, Comm. Phys.-Mat., v. 22, no. 1, 211 p.

——— 1959, On the geology of Lanzarote, Graciosa, and the Isletas (Canarian archipelago): Soc. Sci. Fennicae, Comm. Phys.-Mat., v. 23, no. 4, 117 p.

——— 1962, New contributions to the geology of Grand Canary (Gran Canaria, Canary Island): Soc. Sci. Fennicae, Comm. Phys.-Mat., v. 27, no. 1, 418 p.

——— 1965, Some comments on the structural geology of Gomera (Canary Islands): Acta Geog., v. 18, no. 7, p. 15-21.

Heirtzler, J. R., Dickson, G. O., Herron, E. M., Pitman, W. C., and LePichon, X., 1968, Marine magnetic anomalies, geomagnetic field reversals, and motions of the ocean floor: Jour. Geophys. Research, v. 73, p. 2119-2136.

Heirtzler, J. R., and Hayes, D. E., 1967. Magnetic boundaries in the North Atlantic Ocean: Science, v. 157, p. 185-187.

Holmes, A., 1959, The geologic time scale: Edinburgh Geol. Soc. Trans., v. 17, p. 183.

Kulp, J. L., 1961, The geologic time scale: Science, v. 133, p. 1105-1114.

LePichon, X., and Fox, P. J., 1971, Marginal offsets, fracture zones, and the early opening of the North Atlantic: Jour. Geophys. Research, v. 76, p. 6294-6306.

MacFarlane, D. J., and Ridley, W. I., 1968, An interpretation of gravity data for Tenerife, Canary Islands: Earth Planetary Sci. Letters, v. 4, p. 481-486.

——— 1969. An interpretation of gravity for Lanzarote, Canary Islands: Earth Planetary Sci. Letters, v. 6, p. 431-436.

McDougall, Ian, 1964, Potassium-argon ages from lavas of the Hawaiian Islands: Geol. Soc. America Bull., v. 75, p. 107-128.

McDougall, Ian, and Chamalaun, R., 1966, Geomagnetic polarity scale of time: Nature, v. 212, p. 1415-1419.

McDougall, Ian, and Wensink, H., 1966, Paleomagnetism and geochronology of the Pliocene-Pleistocene lavas in Iceland: Earth Planetary Sci. Letters, v. 1, p. 232-236.

McDowell, F. W., ms, 1966, Potassium-argon dating of Cordilleran intrusives: Ph.D. thesis, Columbia University.

McElhinny, M. W., 1966, An improved method of demagnetizing rocks in alternating magnetic fields: Royal Astron. Soc. Geophys. Jour., v. 10, p. 369-374.

Moorbath, S., Sigurdsson, H., and Goodwin, R., 1968, K-Ar ages of the oldest exposed rocks in Iceland: Earth Planetary Sci. Letters, v. 4, p. 197-205.

Nafe, J. E., and Drake, C. L., 1969. Floor of the North Atlantic—summary of geophysical data: Am. Assoc. Petroleum Geologists Mem. 12 (Symposium on the North Atlantic Geology and Continental Drift), p. 59-87.

Reynolds, J. H., and Spira, R., 1966, Individual tracers for isotopic dilution analysis of rare gases: Nuclear Instr. and Methods, v. 42, p. 225-228.

Rona, P. A., and Nalwalk, A. J., 1970. Post-Early Pliocene unconformity on Fuerteventura, Canary Islands: Geol. Soc. America Bull., v. 81, p. 2117-2122.

Rothe, P., 1964, Fossile strausseneier auf Lanzarote: Natur. u. Museum, v. 94, p. 175-178.

———— 1966, Zum Alter des vulkanismus auf dem östlichem Kanaren: Soc. Sci. Fennicae, Comm. Phys. Mat., v. 31, p. 80.

———— 1967, Petrographische untersuchungen an Basalten und Trachyandesiten ein beitrag zur volcano-stratigraphic von Lanzarote, (Canarische Inslen, Spanien): Neues Jahrb. Mineralogie Mh., v. 2/3, p. 71-84.

———— 1968, .Mesozoische Flysch-Ablagerungen auf der Kanareninsel Fuerteventura: Geol. Rundschau, v. 58, p. 314-322.

Rothe, P., and Schmincke, H. U., 1968. Contrasting origins of eastern and western islands of the Canarian Archipelago: Nature, v. 218, p. 1152-1154.

Rothenplatz, A., and Simonelli, T., 1890, Die Marinen Ablagerungen auf Gran Canaria: Zeitschr. Deutsche Geol. Gesell., v. 42, p. 667-736.

Schmincke, H. U., 1967, Cone sheet swarm, resurgence of Tejeda Caldera, and the early geologic history of Gran Canaria: Bull. volcanol., v. 31, p. 153-162.

———— 1968, Faulting versus erosion and reconstruction of the Mid-Miocene shield volcano of Gran Canaria: Geol. Mitt., v. 8, p. 23-50.

———— 1969, Ignimbrite sequence on Gran Canaria: Bull. volcanol., v. 33, p. 1199-1219.

Schmincke, H. U. and Swanson, D. A., 1967, Laminar viscous flowage structures in ash-flow tuffs from Gran Canaria, Canary Islands: Jour. Geology, v. 75, p. 641-664.

Watkins, N. D., Baksi, A. K., and York, D., 1968, The age of the Picture Gorge Basalt at the type section and at Imnaha, and the maximum duration of a Miocene geomagnetic epoch [abs.]: Geol. Soc. America Ann. Mtg., Mexico City, Program, p. 312-313.

Watkins, N. D., and Richardson, A., 1968. Palaeomagnetism of the Lisbon Volcanics: Royal Astron. Soc. Geophys. Jour., v. 15, p. 287-304.

Watkins, N. D., Richardson, A., and Mason, R. G., 1966a, Palaeomagnetism of the Macaronesian insular region: The Canary Islands: Earth Planetary Sci. Letters, v. 1, p. 225-231.

———— 1966b, Palaeomagnetism of the Macaronesian insular region: Madeira: Earth Planetary Sci. Letters, v. 1, p. 441-475.

APPENDIX

Sample site locations and rock descriptions

The first number is diagram number (figs. 2 to 5). The second number is the original field number. The stratigraphic nomenclature is after Fuster, Santin, and Sagredo (1968), Fuster and others (1968a and b), and Bravo (1964a). Several locations are with respect to local "K" posts, or kilometer markers. Petrographic descriptions are not included but are available from the authors on request.

Lanzarote

Pre-series I Basalts

45 (LZ-106)

Trachybasalt, southwestern cliffs, Punta del Aguila, at sea level. The rock is dark grayish, fine grained, and aphyric.

Basaltic Series I

4 (LZ-3)

Picritic basalt, Point Fariones Scarp, at sea level, immediately west of Orzola, at end of track below small quarry. The rock is dark grayish, medium to coarse grained, porphyritic; alteration products of plagioclase are present.

4 (LZ-104)

A second sample from the same body, 10 m east of LZ-3. The rock is gray and porphyritic.

5 (LZ-103)

Alkali olivine basalt; Point Fariones Scarp, immediately above unit 4. The rock is dark grayish, fine grained, and slightly porphyritic.

12 (LZ-11)

Olivine–augite basalt, Point Fariones Scarp, eight lavas above unit 4, two lavas below a prominent thick reddish sedimentary horizon. The rock is reddish gray and slightly porphyritic.

44 (LZ-105)

Analcite basanite, east coast dominant scarp west of Play Quemada. The rock is grayish, fine grained, and porphyritic.

14 (LZ-102)

Augite olivine basalt; Valle del Fuente Dulce, 800 m west of road to Orzola, at ground level. The rock is very dark gray and porphyritic.

48 (LZ-109)

Plagioclase basalt (olivine poor), west side of Mina de la Cinta, 400 m from road, 20 m above base of slope. The rock is grayish, holocrystalline, and porphyritic.

3 (LZ-101)

Olivine augite basalt, Point Fariones Scarp, uppermost lava at highest point. The rock is dark grayish and porphyritic.

Basaltic Series II, III, and IV

42 (LZ-110)

Alkali olivine basalt, Playa Bastian, at sea level immediately south of entrance to Villa Toledo. The rock is vesicular, dark grayish, and porphyritic.

41 (LZ-112)

Alkali olivine basalt on west side of road from Mozaga to Tiagua, 150 m to north of 13 km post. The rock is grayish, slightly vesicular, and porphyritic.

Fuerteventura

Basement Complex and Submarine Volcanics

14 (FV-19)

Metavolcanic rock, Molinas Canyon, 23 m below capping basalt flow on the northern side, below Llano de la Laguna, 100 m northwest of the dam. Light grayish rock, very fine grained with irregular vesicules filled with calcite and zeolites. The rock shows evidence of low grade metamorphism and was probably of pyroclastic origin.

11 (FV-14)

Alkali syenite, of Montaña Tejeda, on the west side of the road going north from Pajara at 29 km post: this is the largest ring dike or Fuster and others (1968a). The rock is coarse grained, light colored, and mariolitic.

12 (FV-16)

A coarse dioritic rock on the south side of the road south from Vega de Rio de Palmas, at the 32 km post. The rock is surrounded by exfoliating outcrop.

Basaltic Series IVa

20 (FV-23)

Plagioclase basalt, Tostin Cotillo, on sea cliff immediately below the round tower. The rock is dark gray, fine grained, and porphyritic.

Basaltic Series I

4 (FV-2)

Augite basalt (olivine poor), Jandia del Risco-Punta, about 50 m below crest, 400 m from divide, on south side of road to Cofete. The rock is dark grayish, amygdaloidal, and porphyritic.

2 (FV-4)

Augite–basalt (olivine poor), at 250 m level on north side of the scarp above Roque del Moro, just below the pass. Above unit FV-2. Dark grayish porphyritic rock.

1 (FV-5)

Augite basalt (olivine poor) at the highest point on the road crossing the divide to the rock is dark grayish amygdaloidal and porphyritic. Roque del Mara. Above unit FV-4.

23 (FV-30)

Amygdaloidal olivine basalt, Montaña Tindaya, on the road from Casilla del Angel to Puerto del Rosario, 400 m north of km post. The lava is the largest unit above the prominent scree slope, is slightly grayish and porphyritic with amygdoles up to several mm long.

Shield Volcanoes

13 (FV-18)

Olivine basalt, Molinas Canyon, young capping flow on north side just below the dam. The rock is grayish, fine grained, and porphyritic.

18 (FV-24)

Olivine basalt, Barranco Esquinzo, 900 m southeast of Taca, on north side of road. The rock is light grayish, fine grained, and porphyritic.

Gran Canaria

Basaltic Series I

52 (CL-26)

Plagioclase–augite basalt (olivine poor), 3.2 km southwest of junction of San Nicolas-Mogan road, on north side of road. The rock is very fine grained and aphyric with rare amygdales filled with calcite and in some cases zeolites.

22 (CL-11)

Plagioclase–augite basalt, on the east side of the coastal road southwest from Agaete, at 100 m south of the 46 km post. The rock is fine-grained, aphyric, and of subtrachytic texture.

1 (GCU-14)

Plagioclase basalt, on the west side of the road from San Nicolas to Agaete, 200 m south of the 62 km post. The rock is holocrystalline and porphyritic.

64 (GCU-10)

Olivine basalt on roadcut, northwest side of the road through Barranco Tasartico, on Mt. del Lechugal, immediately above the village of Tasartico. The rock is holocrystalline and ankaramitic.

63 (GCU-11)

Plagioclase–augite basalt, 60 m north of unit GCU-10. The rock is holocrystalline and porphyritic.

Ignimbritic–Trachytic Complex

4 (GCU-15)

Alkali trachyrhyolite, on the east side of the coastal road, near Arden Verde, 150 m south of the 57 km post.

52A (GC-95)

Rhyolitic lava, highly oxidized, very fine grained, dark red to maroon colored. At base of section 61 m above road level southwest of and beneath Mt. Horno. The rock is slightly porphyritic.

42 (GC-43)

Soda rhyolite, from a large roadcut on the north side of the road along eastern edge of Mt. de las Carboneras, 400 m south of the 41 km post. The rock is light colored, holocrystalline, and slightly porphyritic.

48 (GC-90)

Alkali rhyolitic tuff, a thick creamy-colored ash flow. Very crystal rich, homogeneous. On roadcut on north side of road 3 km west of Puerto Rico, 38 m above sea level, as part of a 90 m long section of ash-flow. The rock is whitish pumaceous tuff and highly porphyritic.

3 (GCU-6)

Ignimbrite from Montaña Tirma region on northside of road, 250 m southwest of 54 km post. The rock is coarsely porphyritic and light colored.

45 (GCU-32)

Rhyolitic welded tuff, exposed below the phonolite on the west side of the road through the Fataga valley to Maspalomas, at the 2 km post. The rock is reddish pink in color and well banded.

Phonolite Formation

33 (GC-64)

Nepheline phonolite, on the east side of the main coastal road, 5 km south of Las Palmas, 15 m south of the tunnel entrance. The rock is holocrystalline and porphyritic.

33 (GCU-35)

Nepheline phonolite, same location and same body as unit GC-64, on opposite side of the road. The rock is holocrystalline and porphyritic. The anorthoclase phenocrysts are 1 to 6 mm long.

44 (GC-53)

Phonolite (nepheline-bearing), on the east side of the road north from Maspalomas through the Fataga valley, opposite the 5 km post. The rock is dark green, slightly porphyritic.

47 (GC-63)

Phonolite, Fataga valley, on the east side of the road north from Maspalomas 700 m south of the 11 km post. The rock is very fine grained and dark green.

46 (GC-89)

Nepheline–phonolite, a thick very platey body on west side of Barranco de los Vincentes 3.9 km north of Maspalomas at the bottom of the river bed, 400 m south of farmhouse, dipping south at 6°. The rock is dark green gray, massive, and slightly porphyritic.

Roque Nublo Formation

25 (GC-105)

Hauyne–tephrite dike 1.5 m thick. Dipping 65° at N 45° E. In east side of road 2 km above Tejada at 38 km post, as illustrated in Fuster and others (1968b). The rock is light colored and prophyritic.

41 (GCU-29A)

Tephrite, on the east side of the road 100 m south of Mesa de las Burras, elevation 600 m. The rock is dark, fine grained, and porphyritic.

Basaltic Series II

37 (GCU-23A)

Prominent olivine basalt, on east side of the road from Ingenio to Lomo del Caballo, near Llano del Dean, elevation 600 m, about halfway between K-4 and K-5 posts. The rock is holocrystalline and porphyritic.

39 (GCU-25)

Olivine–basalt, from the mouth of Barranco Guagedeque. The rock is dark grayish black, very massive, and slightly porphyritic.

35 (GCU-20)

Olivine basalt, at K-8 post on the south side of the western end of the road going from Ingenio to Lomo del Caballo; elevation 800 m. The rock is slightly vesicular and porphyritic.

34 (GCU-21)

Olivine basalt, 250 m west of unit GCU-20, on north side of the road. The rock is holocrystalline, slightly vesicular, and porphyritic.

La Gomera

Basement Complex Intrusives

2A (20-359)

A syenitic intrusion located 3.1 km east along road from Vallehermoso and 2.1 km south. Hornblende separate from this unit provided by Dr. A. Cendrero.

2 (LG-55)

Hornblende syenite, very variable in outcrop, including pyrite in less fresh parts. Located on south side of road 2.95 km east from Vallehermoso. The rock is very coarse grained and light colored.

Old Basalts

9 (LG-1)

Plagioclase–augite basalt, on north side of road to San Sebastian 150 m east of divide tunnel. The rock is ligh gray, fine to medium grained, and porphyritic.

26 (LG-17)

Olivine basalt, 3.1 km west of San Sebastian on main road, on north side. The rock is light reddish gray, fine grained, and porphyritic.

23 (LG-14)

Olivine–augite basalt, 1.25 km west of unit 26 on same roadcut sequence. The rock is light gray, very fine grained, vesicular, and porphyritic.

22 (LG-13)

Plagioclase basalt (olivine poor), 80 m west of unit 23 in roadcut. The rock is medium gray, fine grained, and slightly porphyritic.

17 (LG-8)

Plagioclase–augite ankaramitic basalt, on very sharp bend in the roadcut sequence, 450 m north and west of unit 22. The rock is light gray, fine grained, and porphyritic.

27 (LG-18)

Olivine–augite basalt, 300 m east of western limit of San Sebastian on north-side of main road.

Horizontal Basalts

4A (LG-59)

Olivine basalt, immediately above unconformity with basement complex, on south side of road at 31 km post east from Vallehermoso. The rock is light gray, fine grained, and porphyritic.

4 (LG-58)

Olivine–augite basalt, 200 m west of 31 km post on road east from Vallehermoso, immediately above basement unconformity. The rock is medium gray, fine grained, and porphyritic.