RADIOMETRIC STUDIES IN MACARONESIA

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With 5 figures and 7 tables

ABSTRACT. — Investigations in Macaronesia date back to 1967-68, and now we have ca. 450 samples at our disposal, exclusive of quite a few rather of archaeological interest.

Distribution of samplings is highly irregular, either in the archipelagos, in individual islands or areas of islands. To date, most such studies refer to the Canary Islands, and on an island basis, to Gran Canaria.

Radiometric samples, via Ar^{40} / Ar^{39} stepwise degassing analyses, give dates as old as 157 MY and by conventional K / Ar methods, 73 MY for basalts in Maio, Cape Verde Archipelago.

With all due respects to the labours of those who have engaged in such isotopic studies, we must confess that apart from yielding more precision to age assignments here and there, there has been little new added to our general temporal stratigraphic appreciations, nor have many perplexing age problems been settled.

INTRODUCTION

The advent of radioactive methods to gauge ages of minerals-rocks began in 1907 with *B. B. Boltwood* using the Pb/U ratios to estimate mineral ages, and since then, isotopic techniques have continued to be refined and improved. Yet even today we must usually reckon with uncomfortably large plus-minus age values, methods of study are elaborate, time-consuming, require espensive equipment, highly-trained technicians, so that such investigations ever lag behind other geological work, and in consequence we so often see expressed the need for more geochronological data.

Macaronesia is no exception here, for radiometric data are generally scarce, very unevenly distributed amongst the islands and archipelagos, with almost no such information for certain islands, yet, on the other hand, quite an abundance for others.

For all the archipelagos, geological information is largely of reconnaissance nature, and thus stratigraphic control for the great majority of radiometric data is neither reliable nor accurate, various formations are still undated stratigraphically, stratigraphers and palaeontologists have still not settled some arguments about this or that point.

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However, with the accelerated pace of geological interest in Macaronesia, it is perhaps pertinent to review here radiometric data obtained for these Mid-Atlantic archipelagos.

AZORES ARCHIPELAGO

Of the nine islands comprising the archipelago (Fig. 1), we have isotopic datings for all except Corvo, the westernmost. (Table I) *Abdel-Monem* et al (1968) published some data for Santa Maria, where oldest volcanics, comprising thin ankaramitic subaerial flows and tuffs, were dated as 8-6 MY, being dissected by many ankaramitic dykes, some of which gave ages of 4 MY. The younger dykes include sediments and

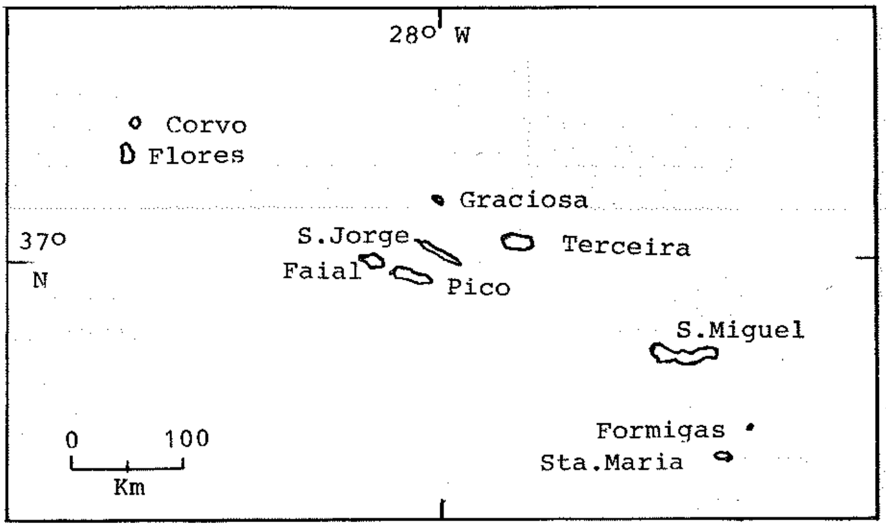

Fig. 1. — Azores Archipelago

submarine volcanics, fossiliferous limestones showing an essentially Vindobonian fauna, with slight tendency towards the Tortonian. (*Zbyseewski & Ferreira,* 1962). These isotopic samplings were taken from just above and below the sedimentaries. *Feraud* et al (1980) took a basalt sample occurring stratigraphically below the sediments, with a mean age of 4.6 MY. A hawaiite from near the top of Pico Alto in the central mountain range, was dated as 5 MY, and a basalt from near Vila do Porto in the W of the island, yielded a slightly older age. These authors remarked that all exposed lavas on the island have undergone alteration to varying degrees, as well as considerable contamination, so the earliest vulcanism can probably be dated as ca. 5.5 MY ago.

Tab. I.-Radiometric Data, Madeira Archipelago

Type Rock	Age MY	Authors	Region
STA. MARIA			
Alk-Ol Basalt	8.12 ± 0.85	A-Monem, 1975	Airport, 70m alt.
Ankaramite	6.08 ± 0.51	ditto	Prainha, S coast
Basalt	5.14 ± 0.40	Feraud, 1980	Near Vila do Porto harbour
Hawaiite	5.11 ± 0.20	ditto	Near summit, Pico Alto
Basalt	Mean 4.6 of 3	ditto	Near Malbusca
Alk-Ol Basalt	4.13 ± 0.35	A. Monem, 1975	Ca. 1Km N of sample 2
FORMIGAS BANK			
Basanitoid	4.65 ± 0.36	A-Monem, 1975	Lighthouse
Basanitoid	4.00 ± 0.31	ditto	35m deep in water, Lighthouse
S. MIGUEL			
Ankaramite	4.01 ± 0.50	A-Monem, 1975	SL, cliff-face, Pta. do Arnel.
Alk-Ol Basalt	3.17 ± 0.28	ditto	Rib. Guilhermo, alt. 290m
Ankaramite	1.86 ± 0.09	ditto	Quarry above Pedreira Village
Tristanite	1.28 ± 0.08	ditto	ditto
Trachybasalt	1.23 ± 0.08	ditto	Rib. Guilhermo, alt. 285m
Tristanite	0.95 ± 0.07	ditto	Quarry above Lomba de Cruz village, alt. 350m
Trachyte	<0.064	Feraud, 1980	SW side of Lagoa Verde
Trachyte	0.32 ± 0.06	ditto	13Km W of Povoação
Trachyte	0.28 ± 0.14	Muecke, 1974	Drillhole at Água de Pau, 950m
Trachyte	0.12 ± 0.024	ditto	ditto, depth of 57m
TERCEIRA			
Comendite	0.75	White, 1976	NE Coast?
Hawaiite	0.30 ± 0.10	Feraud, 1980	180m NNW summit Serra do Cume
Hawaiite	0.30 ± 0.06	ditto	Fonte do Facho
Hawaiite	Mean 0.28 of 2	ditto	Just above Facho sample
Benmoreite	0.029	ditto	Inner cliff, Sta. Barbara caldera
Carbon from Ignimbrite	0.023 ± 350	Shotton, 1973	Angra
Carbon. Wood	0.019 ± 330	ditto 1974	Lajes
Carbon. Wood	0.018 ± 650	ditto 1974	São Mateus
S. JORGE			
Hawaiite	0.55 ± 0.06	Feraud, 1980	Valley immediately E. Fraguera
Hawaiite	0.28 ± 0.09	ditto	Immediately W from Topo
Hawaiite	0.14 ± 0.05	ditto	ESE of Pinguinho da Urze
Hawaiite	0.11 ± 0.07	ditto	ENE of Ribeira Seca
GRACIOSA			
Hawaiite	0.62 ± 0.12	Feraud, 1980	Cam. da Igreja, 440m NNE Guadelup
Trachyte	0.35 ± 0.04	ditto	250m W of Canada Longa
Trachyte	Mean 0.27 of 2	ditto	30m NW summit of Branca
PICO			
Hawaiite	<0.037	Feraud, 1980	150m SSE summit of Arrife
Hawaiite-Mugearite	<0.025	ditto	350m SSW of Terra Alta
FAIAL			
Hawaiite	0.73 ± 0.07	Feraud, 1980	200m N of Espalamaca summit
Hawaiite	0.67 ± 0.09	ditto	200m E of Espalamaca summit
Mugearite	0.21 ± 0.02	ditto	1.4Km SE of Salão
Mugearite	0.03 ± 0.01	ditto	1.3Km NW of Pedro Miguel

Tab. I. (Cont. 1)

FLORES			
Trachyte	0.62 ± 0.05	Feraud, 1980	Immediately N of Lajes
Mugearite	0.61 ± 0.09	ditto	1.2Km S of Pta.Alberniz
Mugearite	Mean 0.55 of 2	ditto	Path Lajes-Faja Lopo Vaz

On Formigas Banks, microscopic islets NE of Sta. Maria, all but covered by seas at high tides, an age for a basanitoid, 4-4.65 MY was recorded by *Abdel-Monem* et al (1975).

For S. Miguel, largest island, *Abdel-Monem* et al (1968) record the first radiometric dates for Macaronesia, 4 MY for the oldest exposed andesitic lavas in the eastern sector, and 0.95 MY for similar rocks in the E. *Muecke* et al (1974), from a coredrill at 1129m depth on the N flanks of Água de Pau (partial core recovery only for the first 148m) through unconsolidated pyroclastics, mud flows, subaerial and submarine lavas and volcanogenic sediments, determined, via K-Ar methods, an age of 120,000 ± 24,000 years for a trachyte 57m below the surface (elevation 72m above SL), and 280,000 ± 140,000 years for a hydrothermally altered submarine flow at a depth of 950m. *Feraud* et al (1980) obtained three K-Ar ages, ranging from 320,000 ± 60,000 years to the present.

For Terceira, *Feraud* et al (1980) gave three values for samples within calderas and volcano-tectonic graben, the Serra do Cume caldera and Vila da Praia graben, being less than 0.3 MY; the Sta. Barbara caldera less than 0.03 MY. However, as per *White* et al (1976), Rb-Sr age of 0.75 MY applies to a comendite — from the NE coastal area ?

From Graciosa we have three determinations by *Feraud* et al (1980), with trachytes, mugearites and hawaiites ranging from 0.62 to 0.27 MY. These authors admit that such ages do NOT agree with the cycles of eruption here as described by *Zbyszewski* et al (1972). *White* et al mentioned 2.5 MY for a comendite, locality uncertain.

Only hawaiites have been isotopically sampled in S. Jorge by *Feraud* et al (1980), all in the southern area of the eastern end of the island. In the more usually accepted definition of hawaiites — olivine-bearing andesine-andesites — though for *Iddings* the presence of olivine qualified naming the rocks basalts — these are not the dominant volcanics as per outcrop areas, but rather alkaline basalts often with olivine but andesine not characteristic. Hawaiites are next in importance area-wise. (*Forjaz & Fernandes* (1975) and the author's observations). The hawaiites have been assigned ages of up to 0.55 MY by *Feraud* et al, but as the eastern end of the island is also taken by them to be the oldest part, the isotopic dates are not thus representative of here, and none doubt that S. Jorge is older than Pleistocene, *Forjaz & Fernandes,* e.g. considered their Complexo Volcanico do Tope to be Pliocene.

Two hawaiite samples from Pico, again in the eastern part, yielded to *Feraud* et al (1980) ages of less than 37,000 years, the eastern sector being recognized by *Zbyszewski* et al (1962) to be youngest, except that here, the highest point, Topo, is taken to correspond to the remains of the oldest volcano on the island, and *Woodhall* (1974) believed that at Topo occur the oldest rocks in Pico. The isotopic samples are young indeed, but publications available do not hint as to the age of the western part of the island. For both S. Jorge and Pico, the author favours an U. Miocene rather than Pliocene age for these islands.

Five determinations were made in Faial by *Feraud* et al (1980), one of an 18th. century eruption (vd. *Mitchell-Thomé* (1981)). Hawaiite and mugearite samples taken from the inner wall of the WNW-trending graben across the island, indicate that this structure has a maximum age of 0.73-0.67 MY. Two mugearite samples of the formation pre-dating the principal caldera, gave values of 0.21 MY and a young age of 30,000 years, a large range indeed, which does not define very neatly the age of this massive volcanic feature.

Of the western islands, only Flores rocks have been sampled by *Feraud* et al (1980). A mugearite from near the N coast was dated as 0.61 MY; two other samples from the S coastal area yielded 0.55 MY for mugearite and 0.62 MY for trachyte. *Zbyszewski* (1968), *Zbyszewski* et al (1968) indicated that the Lajedo Pyroclastic Complex of the extreme SW part of the island was the oldest unit, but rocks of this same Complex outcrop in the general area where the 0.55 MY mugearite was taken in the NW coastal area, similar rocks also occurring in the NE coastal area.

DISCUSSION

Zbyszewski & Ferreira (1962) assigned a Vindobonian age to fossiliferous limestones, tuffs, agglomerates and breccias exposed chiefly along coastal sections and up valleys in Sta. Maria, and all earlier workers had attributed such rocks essentially a similar age, ranging from Aquitanian up to Pontian. This would then place them in the 10-5 MY range. But *Abdel-Monem* et al (1975) have contested the views of *Zbyszewski & Ferreira*, claiming that the planktonic foraminifera have a range from M. or U. Miocene to the present, that two species *(Globorotalia puncticulata* and *G. hursuta)* indicated ages of ca. 4.2 MY and 5-5.6 MY respectively. They therefore argued that coquina limestones were deposited between 6 and 4 MY ago, thus of Plaisancian-Dacian age, i.e. U. Miocene-L. Pliocene. Their 6.08 MY sample was collected from below the coquina zone, whilst their 4.13 MY sample came from above the same zone. On the other hand, *Feraud* et al (1980) believed that the error limits of ± 0.85 MY for the *Abdel-Monem* 8.1 MY sample, was in all likelihood too small because of significant atmospheric contamination. This might still place this sample within the Pontian, perhaps ranging down to Tortonian.

Abdel-Monem et al (1975) suggested that their Formigas samples were likely equivalents in age of the post-coquina basalts of Sta. Maria. *Feraud* et al concluded that in Sta. Maria, the earliest vulcanism is more appropriately placed at ca. 5.5 MY ago, i.e. topmost Miocene. But the presence of fossiliferous limestones, chiefly of Vindobonian age, sandwiched between *Feraud* et al's samples, and the determination by *Abdel-Monem* et al (1968) of lavas of 8-6 MY in the island, would seem to argue that the age of Sta. Maria is more likely lower M. Miocene, perhaps even L. Miocene, though again these latter authors were of the opinion that the fossiliferous sediments were younger than Vindobonian and deposited some 6-4 MY ago. Thus, as of the present, confusions, paradoxes exist in Sta. Maria.

For Graciosa, *Feraud* et al (1980) obtained an oldest age (0.62 MY) from Serra das Fontes region, 0.35 MY from Serra Dormida region, and 0.27 MY from Serra Branca area. However, *Zbyszewski* et al (1972) claimed a volcanic sequence thus: (1) initial submarine trachytic eruptions, now forming Serra Branca and Dormida, (2) basalt and peridotitic andesites, present in the Serra das Fontes, (3) Caldeira volcano formation, (4) andesites and basalts on the upper slopes of Serra Branca and Dormida, (5) Quaternary essentially basaltic outpourings of the NW plateau area, (6) Holocene basaltic eruptions of Pico do Timão, central E coast. There is obviously some conflict here with the results of *Feraud* et al. We must further note that *White* et al (1976), on the basis, of Sr87/Sr86 ratios, estimated the age of a comenditic trachyte of the island as having an 'apparent age' of 2.5 MY — exact location not given, but seems to come from the eastern part of Serra Dormida. This might be an indication of an approximate age for *Zbyszewski* et al's initial volcanic phase, hence L. Pliocene, but we have no firm assurance that Graciosa is a Pliocene island. *Krejci-Graf* (1961), claimed that the oldest Graciosa rocks — trachytes — occurred at the western extremity of the Serra Branca, by Ponta Branca.

For Flores, we must seriously question if vulcanism dates from only some 0.6 MY ago, as per the findings of *Feraud* et al. It is true that this island, along with Corvo, are the Azores islands closest to the Mid-Atlantic Ridge, W thereof and Faial E thereof, and the isotopic data would therefore support the contention that islands closer to this feature are younger, age-increase extending the further away the islands are located from the Ridge, but we would question this neat island-age arrangement with respect to the Ridge, for ocean-floor spreadings, subduction zones are based only on theories, not facts.

MADEIRA ARCHIPELAGO

Three island groups comprise the archipelago (Fig. 2), Madeira proper (89% of area), Porto Santo (8.5%) and Ilhas Desertas (ca. 2.5%).

Eight radiometric dates are available for Madeira, eight for Porto Santo and one offshore sample — a mere eighteen terrestrial samples for an area of 810 km^2.

Volcanics assume overwhelming importance in Madeira proper, are total in Ilhas Desertas, but in Porto Santo there are considerable areas of sedimentaries, negligible in the main island.

Watkins et al (1966), *Watkins & Abdel-Monem* (1971) and *Watkins* (1973) reported on palaeomagnetic data for Madeira proper, studies being

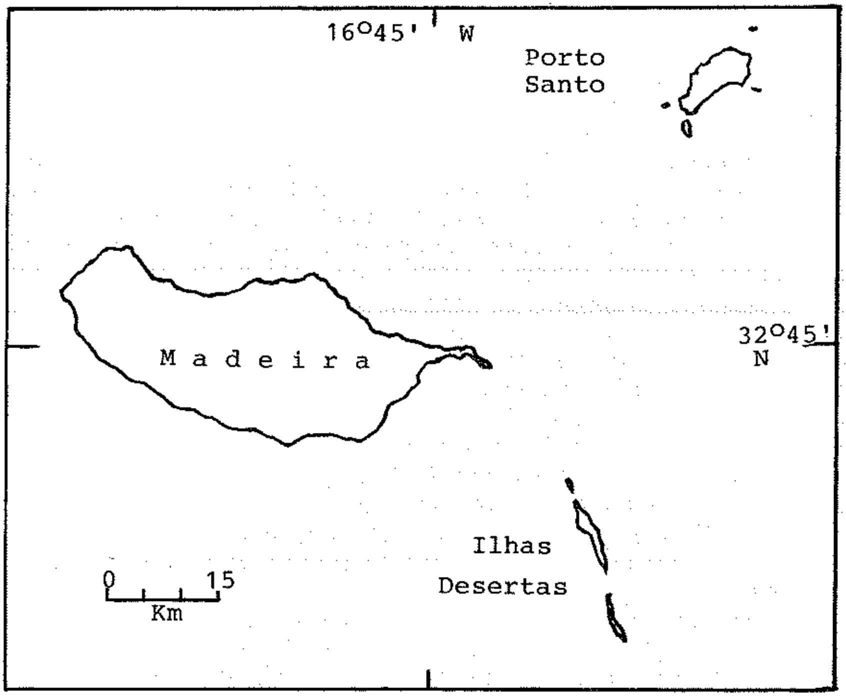

Fig. 2. — Madeira Archipelago

made only in the eastern portion, not always are localities clearly defined, and further, some duplication of datings occur. K-Ar values are given for ten samplings from twenty-eight palaeomagnetically investigated. Eight lavas isotopically recorded are in a single sequence, which also contains sedimentary horizons, dates ranging from 1.76 to 0.74 MY. (Table II). The 3.05 MY basalt comes from high in the interior (near Cabeço do Faisca, Route 103), where the Post-Miocene Volcanic Complex outcrops. *(Zbyszewski* et al, 1975). Both the Jaramillo and Gilas polarity events are thus represented in the main island.

Ferreira (1969) for Porto Santo reported dioritic xenoliths within the volcanics, three basalts yielding ages between 14 and 12 MY, the xenoliths being older. These volcanics are intimately associated with chiefly calcareous sediments, faunistically assigned to the Miocene, mostly Vindobonian (*Silva,* 1959). There are reasons for assuming that this island

Tab. II. -Radiometric Data, Madeira Archipelago

Type Rock	Age MY	Authors	Region
MADEIRA			
Ol-Aug Basalt	3.05 ± 0.15	Watkins, 1971	E side, N-S roadcut, above junct Ribeiras Frio and Lenha
Alk-Ol Basalt (duplicated)	1.76 ± 0.07	ditto	Exact locations not given, but in general Porto Novo-Gaula-Santa Cruz ãrea
Amygdal Ol Basalt	1.64 ± 0.03	ditto	
Ol-Aug Basalt	1.15 ± 0.06	ditto	Culvert, N side road, head of Rib. Santa Luzia
Alk-Ol-Plag Basalt	1.05 ± 0.07	ditto	See above for inexact locations
Alk-Ol Basalt (duplicated)	1.03 ± 0.05	ditto	
Alk-Ol Basalt	0.89 ± 0.05	ditto	Adjacent, road referred below
Plag-Aug Basalt	0.74 ± 0.04	ditto	End of roadcut, head of Rib. de Santa Luzia
Pelecypod Shell	0.014	Montaggioni 1969	Offshore from Madeira, depth 1900m
PORTO SANTO			
Sub-Basalt Flow	14.2 ± 1.4	Ferreira, 1969	Ponta da Calheta
Basalt	13.5 ± 0.4	ditto	Pico de Concelho
Basalt	12.4 ± 0.4	ditto	400m ESE, Fonte de Areia
Patella Shelly Limestone	≥ 0.043	Lietz, 1971	Mouth of Rib. da Vigia
ditto	≥ 0.0415	ditto	ditto
ditto	≥ 0.0395	ditto	ditto
Aeolinite	0.02157 ± 350	ditto	Fonte de Areia
ditto	0.01348 ± 120	ditto	Porto dos Frades

is older than Madeira proper, e.g. more advanced geomorphologic evolution (*Mitchell-Thomé,* 1979). Aeolinites and *Patella* shelly limestones of Porto Santo, as per C-14 datings by *Lietz & Schwarzbach* (1971), gave ages of 43,000 years and less, these fossils occurring on marine conglomeratic terraces at the mouth of the Rib. da Vigia, lying 0-3 m above present SL.

Likewise of interest is a radiocarbon dating of 14,000 years for *Glycimeris pillosus* shells at a depth of 1900 m off the S coast of Madeira proper, a fauna whose normal habitat is ca. 100 m, thus suggesting profound subsidence in the Quarternary. (*Montaggioni,* 1969).

DISCUSSION

Geological gleanings of the archipelago date back to 1811 (*Bennet*); in 1857 the first fossil flora was mentioned by *Heer* and in 1851 the first fossil fauna was described by *Lowe*, and Miocene sediments have been recognized for some 130 years. Continued studies have amply confirmed a Miocene stratigraphy for the sedimentaries, the archipelago being taken as scarce older than Aquitanian. Agreed, general detailed studies in the archipelago are all but non-existent, although adequate geological maps are available of Madeira proper (*Zbyszewski* et al, 1975) and Ilhas Desertas (*Zbyszewski* et al, 1973).

We would question what credence one can place in Montaggioni's postulating great subsidence on the basis of a solitary value for a single fossil now lying evidently beyond its normal habitat-tides and currents could easily have removed the fossil to such depths.

CANARIES ARCHIPELAGO

More radiometric studies have been made here than elsewhere in Macaronesia, but distribution of such is very uneven, Gran Canaria receiving most and La Palma least. When one recognizes that both Tenerife and Fuerteventura are larger than Gran Canaria, yet have only about one-quarter and one-half respectively as many isotopic results, this disparity is well exemplified. (Fig. 3, Table III).

Oldest geochronologically dated samples from the various islands are: Fuerteventura, 38.6 MY; Tenerife, 20.6 MY; Gomera, 19.3 MY; Lan-

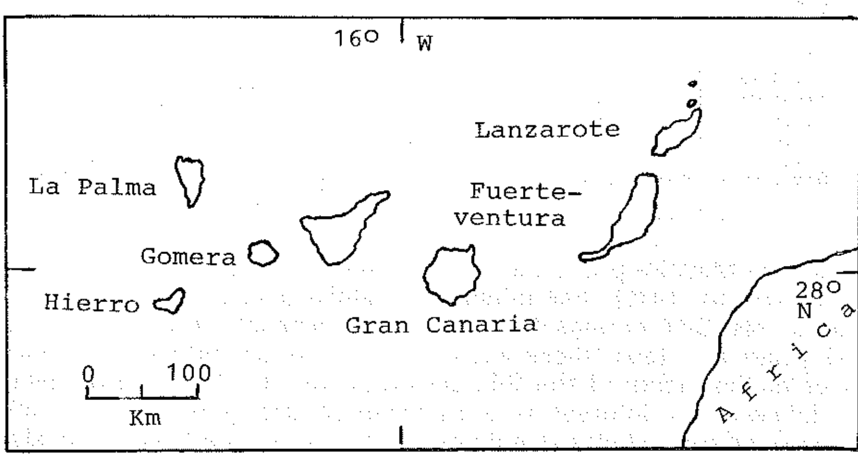

Fig. 3. — Canaries Archipelago

Tab. III. -Radiometric Data, Canaries Archipelago.

Type Rock	Age MY	Authors	Region
LANZAROTE			
Trach-Basalt	19.00 ± 0.68	A-Monem, 1971	Punta Aguila, SL
Picr-Basalt	10.60 ± 1.12	ditto	10m W Pta. Fariones scarp W Orzola, at SL
Ol Basalt	9.25 ± 0.57	ditto	Pta. Fariones scarp, W Orzola
Basanite	7.68 ± 0.53	ditto	Scarp W of Playa Quemada
Aug-Ol Basalt	7.00 ± 0.34	ditto	Valle F. Dulce, W Orzola road
Plag Basalt	6.37 ± 0.13	ditto	Mina Cinta, 20m above slope base
Alk-Ol Basalt	6.00 ± 0.15	ditto	Punta Fariones scarp
Ol-Aug Basalt	5.82 ± 0.36	ditto	ditto, highest point
ditto	5.30 ± 0.19	ditto	Pta. Fariones, W of Orzola
Alk-Ol Basalt	0.96 ± 0.10	ditto	Playa Bastian, by Villa Toledo
ditto	0.034 ± 0.03	ditto	Mozaga-Tiagua road, 150m E of 13Km signpost
FUERTEVENTURA			
Alk Syenite	38.6 ± 3.75	A-Monem, 1971	Mont. Tejeda, Pajara Rd, 29Km signpost
Metavolcanic	35.30 ± 0.92	ditto	Molinos canyon, bel. Llano Laguna
Metadolerite	22.4 ± 3.3	Rona, 1970	E-SE of ca. 8Km from Pto. Pena
Basalt	22.3 ± 0.6	ditto	Mouth Barr. Molinos, N side cliff
Ol Basalt	22.3 ± 0.4	ditto	ditto
Horn Gabbro	20.80 ± 0.52	A-Monem, 1971	Road S Vega Palmas, 32Km post
Plag Basalt	20.60 ± 0.94	ditto	Sea cliff, Tostin Cotillo
Diorite	19.0 ± 9	Grunau, 1975	E-SE of ca. 8Km from Pto. Pena
Horn Gabbro	18.40 ± 0.32	A-Monem, 1971	Road S Vega Palmas, 32Km post
Horn Andesite	18.0 ± 0.22	Rona, 1970	Mouth Barr. Molinos, N side
Syenite	18.0 ± 10	Grunau, 1975	E-SE of ca. 8Km from Pto. Pena
Volcanite	16.8 ± 4.1	ditto	ditto
Aug Basalt	16.55 ± 0.61	A-Monem, 1975	Jandia Risco-Punta, 50m bel/top
Alk Basalt	15.9 ± 1.6	Grunau, 1975	E-SE of ca. 8Km from Pto. Pena
ditto	15.88 ± 1.68	Rona, 1970	Roque Moro, 250m, N scarp side
Basalt	14.4 ± 0.2	ditto	Mouth Barr/Molinos, N side
Aug Basalt	14.30 ± 0.52	A-Monem, 1971	Roque Moro, above Mont. Tindaya sample
Gabbro	12.1 ± 0.5	Rona, 1970	Mouth Barr. Molinos, N side
Ol Basalt	11.80 ± 0.33	A-Monem, 1971	Mont. Tindaya, Casilla-Rosário rd
ditto	4.25 ± 0.44	ditto	Molinos canyon, N side, below dam
ditto	1.83 ± 0.24	ditto	Barr. Esquinzo, 900m SE of Taca
Calcarenite	≥0.039	Rona, 1970	Mouth Barr. Molinos, N side
GRAN CANÁRIA			
Plag Basalt	16.12 ± 0.40	A-Monem, 1971	S. Nicolas-Agaete Rd, 62Km post
ditto	15.70 ± 0.27	ditto	ditto
dittc	15.40 ± 0.26	ditto	Rd. SW from Agaete, 46Km post
Trach-Rhyolite	15.00 ± 0.38	ditto	Near Anden Verde, 57Km post
Plag Basalt	15.00 ± 0.20	ditto	Junction S. Nicolas-Mogon roads
Basalt	13.9 ± 0.3	McDougall 1976-77	Barr. Tazartico, N cliff
Alk Rhyolite	13.9 ± 0.3	ditto	Barr. Mogon, 1.6Km from SW coast
Basalt	13.8 ± 0.3	ditto	Mouth Barr. Tazartico, N cliff
Rhy Ignimbrite	13.8 ± 0.3	ditto	Anden Verde, S. Nicolas-Agaete Rd
Tra Ignimbrite	13.8 ± 0.3	ditto	Barr. Taurito, cutting W side
Hawaiite	13.7 ± 0.3	ditto	S. Nicolas-Agaete Rd, 60-61Km post
Rhyolite	13.7 ± 0.3	ditto	M. Blanca, S. Nicolas-Agaete road
ditto	13.7 ± 0.3	ditto	Barr. Mogon, 1.6Km from road junction

Tab. III (Cont.1)

Basalt	13.6 ± 0.3	McDougall 1976-77	Mouth Barr. Tazartico, N cliff
Alk Basalt	13.6 ± 0.3	ditto	Barr. Guigui, 0.5Km SE E1 Puerto
Rhy Ignimbrite	13.6 ± 0.3	ditto	Barr. Taurito, roadcut, W side
Alk Basalt	13.5 ± 0.3	ditto	Barr. Tazartico, 0.9Km from coast
ditto	13.5 ± 0.3	ditto	Barr. Guigui, 0.5Km SE E1 Puerto
Hawaiite	13.5 ± 0.3	ditto	S. Nicolas-Agaete Rd., 60-61Km post
Amphibole Ignimbrite	13.5 ± 0.3	ditto	S. Nicolas-Agaete Rd, Anden Verde
Pantell-Ignimbrite	13.4 ± 0.3	ditto	Barr. Raurito, 300m from coast
Rhy Ignimbrite	13.4 ± 0.3	ditto	S. Nicolas-Agaete Rd, Anden Verde
Pumice Tuff	13.4 ± 0.3	ditto	ditto, 60Km post
Hawaiite	13.4 ± 0.3	ditto	ditto
Amphibole Ignimbrite	13.4 ± 0.4	ditto	S. Nicolas-Agaete Rd, Anden Verde
Alk Rhyolite	13.4 ± 0.4	ditto	ditto, 60Km post
ditto	13.3 ± 0.3	ditto	S. Nicolas-Mogon Rd, by Veneguera
Hawaiite	13.3 ± 0.3	ditto	S. Nicolas-Agaete Rd, 60Km post
Rhy Tuff	13.30 ± 0.23	A-Monem, 1971	Fataga-Maspalomas Rd, 2Km post
Hawaiite	13.2 ± 0.3	McDougall 1976-77	S. Nicolas-Agaete Rd, 61Km post
ditto	13.2 ± 0.3	ditto	Barr. Guigui, 1Km E E1 Puerto
Rhy Ignimbrite	13.2 ± 0.3	ditto	S. Nicolas-Agaete Rd, Anden Verde
Fel Ignimbrite	13.10 ± 0.50	A-Monem, 1971	Mont. Tirma, SW of 54Km post
Rhy Tuff	13.10 ± 0.34	ditto	3Km SW Puerto Rico, roadcut
Fel Ignimbrite	13.1 ± 0.3	McDougall 1976-77	Mouth Barr. Taurito, E side
Basalt	13.1 ± 0.3	ditto	Barr. Tazartico, 0.9Km E of coast
Hawaiite	13.1 ± 0.3	ditto	200m N Puerto Aldea
ditto	13.0 ± 0.3	ditto	600m E Pto. Aldea, W coast
Na Rhyolite	12.65 ± 0.11	A-Monem, 1971	Mt. Carboneras, 400m S 41Km post
Tra Ignimbrite	12.6 ± 0.3	McDougall 1976-77	Betw. Barrs. Taurito and Mogan
Tra Phonolite	12.6 ± 0.3	ditto	ditto
Trach Basalt	12.5 ± 0.3	ditto	W of Barr. Taurito
Alk Feldspar in Phonolite	12.2 ± 0.3	ditto	Below Paradilla dam, S. Nicolas Road
Rhy Tuff	12.20 ± 0.22	A-Monem, 1971	Road SW and below Mte. Horno
Bio in Syenite	11.9 ± 0.3	McDougall 1976-77	Below Paradilla dam, S. Nicolas Road
ditto	11.8 ± 0.3	ditto	ditto
Alk Feldspar in Phonolite	11.7 ± 0.4	ditto	Maspalomas-Fataga Rd, Km 11-12
Plag Basalt	11.50 ± 0.19	A-Monem, 1971	Tasar, by Barr. Tazartico
Alk Feldspar in Phonolite	11.1 ± 0.3	McDougall 1976-77	Maspalomas-Fataga Rd, Km 11-12
ditto	11.0 ± 0.3	ditto	ditto
Phonolite	10.90 ± 0.27	A-Monem, 1971	Fataga valley, N of Maspalomas
Ne Phonolite	10.60 ± 0.20	ditto	Barr. Vincentes, 4Km N Maspalomas
Phonolite	10.30 ± 0.13	ditto	N of Maspalomas, 5Km post
Ol Basalt	10.20 ± 0.61	ditto	Barra. Tazartico, above Tasar
Ne Phonolite	9.80 ± 0.11	ditto	5Km S Las Palmas, entrance to tunnel
Alk Feldspar	9.8 ± 0.2	McDougall 1976-77	Pto. Palo, 6.5Km S Las Palmas
Phonolite	9.7 ± 0.2	ditto	ditto
ditto	9.60 ± 0.11	A-Monem, 1971	5Km S Las Palmas, entrance to tunnel
Ne Phonolite	8.7 ± 0.1	McDougall 1976-77	Paradillo dam, 200m downstream

Tab. III (Cont.2)

Ol Nephelinite	5.48 ± 0.14	McDougall 1976-77	Barr. Tazartico,900m from W coast
ditto	4.95 ± 0.14	ditto	ditto
ditto	4.86 ± 0.15	Lietz, 1975	Maspalomas-Tablero Rd, 56Km post
Alk Basalt	(4.38 (4.43 ± 0.15	ditto	Mesa Junquillo, 375m above SL
ditto	(4.25 (4.37 ± 0.09	ditto	Lomo Ingleses, NW Las Palmas
ditto	(3.99 (4.02 ± 0.10	ditto	Summit Monte Molinos
ditto	3.96 ± 0.10	ditto	Barr. Tirajana, E of Aldea Blanca
ditto	3.88 ± 0.07	McDougall 1976-77	Barr. Siberio, path to Chorillo
Phonolite	3.86 ± 0.06	ditto	Artenara-S.Nicolas Rd, 54Km post
ditto	3.81 ± 0.09	ditto	Tejada-S.Bartolomé Rd, 52Km post
Ankaramite	3.77 ± 0.15	Lietz, 1975	Las Palmas, N side Barr. Negro, above La Laja
ditto	3.77 ± 0.08	ditto	Lomo Grande, above Tenoya
Tephrite	3.75 ± 0.12	A-Monem, 1971	2Km above Tejeda, 38Km post
Hau Phonolite	(3.65 (3.71 ± 0.18	Lietz, 1975	Risco Blanca, Barr. Tirajana
Tephrite	3.50 ± 0.09	A-Monem, 1971	100m S of Mesa Burras
ditto	3.49 ± 0.08	McDougall 1976-77	La Forteleza, Barr. Tirajana
ditto	3.40 ± 0.08	ditto	ditto
Ol Nephelinite	2.98 ± 0.07	ditto	2.7Km S Sta. Lucia, Aguimes Rd.
Ol Basalt	2.80 ± 0.08	A-Monem, 1971	Ingenio-Caballo Rd, near 8Km post
Ol Nephelinite	2.76 ± 0.08	Lietz, 1975	Barr. Tirajana, E of Aldea Blanca
ditto	2.70 ± 0.07	McDougall 1976-77	2.9Km S Sta. Lucia, Aguimes Rd
ditto	2.66 ± 0.10	Lietz, 1975	1Km dam site, Llanos Paz
ditto	2.55 ± 0.05	McDougall 1976-77	Tejeda-Artenara Rd, Mirador
ditto	2.37 ± 0.04	ditto	ditto
ditto	2.27 ± 0.06	ditto	Bed, Barr. Guayedeque, near source
Ol Basalt	2.20 ± 0.11	A-Monem, 1971	Ingenio-Caballo Rd, 8Km post
Ol Nephelinite	2.18 ± 0.06	McDougall 1976-77	Ingenio-Pasadilla Rd, 8Km post
Ol Basalt	2.05 ± 0.32	A-Monem, 1971	Mouth, Barr. Guadedeque
ditto	1.96 ± 0.10	ditto	Ingenio-Caballo Rd, by Ll. Dean
Basanite	1.89 ± 0.05	McDougall 1976-77	M. Garanon, 500m E rim of Marteles
Nephelinite	1.79 ± 0.05	ditto	4Km SE Tejeda, Nievos-Teide Rd.
Basanite	1.62 ± 0.05	ditto	Ingenio-Pasadilla Rd, 8Km post
ditto	1.26 ± 0.05	Lietz, 1975	Barr. Guinigada, 130m above SL
Tephrite	(0.53 (0.55 ± 0.02	ditto	Mte Cardones, by Punta Arucas
Hau Phonolite	(0.30 (0.33 ± 0.03	ditto	Mouth Barr. Cardones, W side
Basanite	0.15 ± 0.01	McDougall 1976-77	Source of Barr. Guayedeque
Tree Wood	0.0031 ± 50	Nogales, 1969	Caldar-Tejeda Rd, Km 56-57 junct
<u>TENERIFE</u>			
Plag Basalt	20.6	A-Monem, 1969	?
Ol-Aug Basalt	15.68 ± 1.60	A-Monem, 1972	Taganana, Anaga Peninsula
Ol Basalt	7.18 ± 0.57	ditto	Teno Pen., 80Km post, N-S road
Ol-Aug Basalt	6.55 ± 0.26	ditto	Roadcut, Buenavista-Teno Rd.
Ol Basalt	6.10 ± 0.18	ditto	ditto
Trachyte	5.35 ± 0.11	ditto	Teno Pen, 80Km post, N-S road

Tab. III (Cont. 3)

Aug Basalt	4.65 ± 0.70	ditto	S. Andreas valley, 19Km, Anaga
ditto	1.85 ± 0.37	ditto	Ladera Guimar scarp; roadcut top
Ol-Aug Basalt	1.63 ± 0.11	ditto	N of Candelaria, 20Km post
Trachyte	1.54 ± 0.17	ditto	Mte. Izana road Meteor. Observ
Ol-Aug Basalt	1.52 ± 0.15	A-Monem, 1972	Ladera Guimar scarp, roadcut top
Phonolite	1.35 ± 0.02	ditto	Cliff, Los Realejos, 12Km post
ditto	1.27 ± 0.04	ditto	Vilaflor Rd, 200m S 65Km post
ditto	1.22 ± 0.04	ditto	ditto
Trach Basalt	1.03 ± 0.05	ditto	Tigaiga Rd, 100m S of 13Km post
Phonolite	0.95 ± 0.06	ditto	Arico-Grandilla Rd, 79Km post
Plag Basalt	0.88 ± 0.55	ditto	Ladera-Guimar scarp, 800m below Barr. Teguigo source
ditto	0.86 ± 0.22	ditto	Ladera-Guimar scarp, lowest lava in roadcut
ditto	0.84 ± 0.28	ditto	Ladera Guimar scarp
ditto	0.84 ± 0.05	ditto	550m W 56Km post, Playa Socorro
Aug Basalt	0.81 ± 0.09	ditto	Roadcut E end Ladera Guimar scarp
Phonolite	0.67 ± 0.01	ditto	Ucana, roadcut at 55Km post
ditto	0.67 ± 0.01	ditto	Barr. Rambler, 16Km post E side
Alk Trachyte	0.56 ± 0.04	ditto	Road N Grandilla, 72Km post
ditto	0.53 ± 0.03	ditto	Suazal, quarry at 21Km post
ditto	0.20 ± 0.08	ditto	Road N Vilaflor, 64Km post
Phonolite	<0.20	ditto	Los Azulejos, S rim Las Canadas
GOMERA			
Horn Syenite	19.30 ± 1.58	A-Monem, 1971	3.1Km E Vallehermoso, 2.1Km S
ditto	14.60 ± 0.67	ditto	2.95Km E Vallehermoso
Plag Basalt	12.00 ± 0.39	ditto	150m E of tunnel, S. Sebastian Rd
Ol Basalt	11.40 ± 0.80	ditto	3.1Km W S. Sebastian, N sideroad
Plag Basalt	8.86 ± 0.13	ditto	530m above 300m E, W limit S. Sebastian, N side
ditto	8.64 ± 0.14	ditto	450m above same place
Ol Basalt	8.42 ± 0.29	ditto	300m E, W limit S. Sebastian, N side
ditto	5.23 ± 2.13	ditto	200m W 31Km post, Vallehermoso Rd
ditto	4.69 ± 0.12	ditto	ditto
LA PALMA			
Ol Basalt	1.57 ± 0.09	A-Monem, 1972	Barr. Augustias, N side, 62Km post
Plag Basalt	1.02 ± 0.03	ditto	Barr. Augustias, above pump station
Ol Basalt	0.81 ± 0.09	ditto	Barr. Lomados, N side, 62Km post
ditto	0.76 ± 0.09	ditto	Barr. Lomados, N side roadcut, 25Km post
Phonolite	0.60 ± 0.30	ditto	Mte. S. Antonio, S of Fuencaliente
HIERRO			
Ol-Aug Basalt	3.05 ± 0.04	A-Monem, 1972	Wall El Golfo, above Frontera
Plag Basalt	0.74 ± 0.04	ditto	14Km post, S. Andres-Valverde Rd
ditto	0.70 ± 0.07	ditto	Road into El Golfo, below Mte. Tabano, 200m up
Ol Basalt	0.19 ± 0.03	ditto	Same place, by road
ditto	0.19 ± 0.01	ditto	Top of El Golfo scarp
Carbonized Veg. Matter	0.00674 ± 150	Pellicer 1977	Vol. Tanganasoga, in El Golfo
ditto	0.0042 + 100	ditto	ditto
Carbonized Wood	0.0029 + 130	Hausen, 1973	?

zarote, 19 MY; Gran Canaria, 16.1 MY; Hierro, 3.1 MY and La Palma 1.6 MY. For some twenty years or so, other geological studies had concluded that Fuerteventura was relatively old, probably the oldest archipelago island. «Basements Complexes» were believed to be present in Fuerteventura, Lanzarote, Tenerife, Gomera and La Palma at least before the advent of geochronological work, and such samplings as have been done would appear to confirm greater ages here, but present isotopic evidence is too impoverished to add concrete proof of this. Available datings for the islands range thus: Lanzarote, 19 MY to 34,000 years; Fuerteventura, 38.6-1.83 MY; Gran Canaria, 16.12-0.15 MY; Tenerife, 20.6-0.20 MY; Gomera, 19.30-4.69 MY; La Palma, 1.57-0.60 MY; Hierro, 3.05.0-19 MY — all for igneous rocks only. Hierro has been believed the youngest archipelago island on geological considerations, a product of Pliocene times, (*Hausen*, 1973, *Pellicer*, 1977), and the young value obtained for La Palma is not significant in this respect, as it was obtained from lavas unconformably overlying the «Basement Complex», which certainly is considerably older, likely comparable in age to that in Fuerteventura, Lanzarote, Tenerife and Gomera, which are likely comparable in that they date from the L. Neogene. *Schmincke* (1976) claimed that the shields of Gran Canaria and Fuerteventura were oldest — M. Miocene, the «Basements» of Gomera and Lanzarote were U. Miocene whilst that of Tenerife was of L. Pliocene age. The publications of *McDougall & Schmincke* (1976-77) and *Schmincke* (1979) specifically treated of Canarian geochronology, the former of Gran Canaria only. This former paper pigeon-holes the forty-six isotopic samples studied by them, with stratigraphic nomenclature devised by *Schmincke* in 1976, from oldest to youngest thus: Guigui Fm, 13.9-13.1 MY; Hogarzales Fm; 13.7-13 MY; Mogan Fm, 13.9-12.5 MY; Montana Horno Fm, 13.4 MY; Fataga Fm; 12.6-9.7 MY; Tejeda Fm, 11.9-9.7 MY; El Tablero Fm, 5.48-4.95 MY; Roque Nublo Group, 3.88-3.40 MY; Post-Roque Nublo Group, 2.98-0.15 MY.

Abdel-Monem et al (1971) quoted five datings older than *McDougall & Schmincke* for Gran Canaria, and indeed they stated that their Basalt Series I (*Fuster* et al, 1968) samplings indicated that: «It is thus quite possible that volcanic activity on this island can be extended back *at least* (Italics RCM-T) 17 to 18 m.y. ago». Seven erosional unconformities occur within *Schmincke*'s stratigraphic table for Gran Canaria, yet there is a relatively short time-range of some 1.4 MY within the Guigui-Hogarzales-Mogan-Horno formations, and further, there is overlapping in age between the Mogan-Fataga-Tejeda formations, representing partial synchronology.

Abdel-Monem et al (1971) studied twenty-three samples from Gran Canaria, adjusting these to the stratigraphic chart of *Fuster* et al (1968), the allotments being: Ages 10.20-6.12 MY, Basaltic Series I; 15-12.20 MY, (Ignimbritic) Syenitic-Trachytic Complex; 10.90-9.60 MY, Phonolitic Series; 3.75-3.50 MY, Roque Nublo Series; 2.80-1.96 MY, Basaltic Series II.

In turn, *McDougall & Schmincke* correlated their own table with that of *Fuster* et al as follows:

McDougall & Schmincke	*Fuster* et al
Post-Roque Nublo Group	Basalt Series II, III, IV
Roque Nublo Group	Roque Nublo Series
Tablero	Pre-Roque Nublo Series (?)
Fataga-Tejeda	Phonolitic Series
Mogan	Syenitic-Trachytic Complex
Guigui-Hogarzales	Basalt Series I

The neat summation, correlation and assessments of volcanic evolutions as per *Abdel-Monem* et al and *McDougall & Schmincke* however, as will be mentioned below, are far from being in agreement with the views of *Storetvedt* and co-workers, even though *Schmincke,* along with *Lietz* and *McDougall,* have done more isotopic investigations on Gran Canaria than anyone else.

For Tenerife, *Abdem-Monem* et al (1972) recorded twenty-six datings. Their oldest values, for the Teno and Anaga peninsulas, conform to what had been long determined via geological means. 15.68 MY is the oldest date recorded by them, in the Anaga area, but in his doctoreal thesis of 1969, *Abdel-Monem* mentioned an age of 20.6 MY for a plagioclase basalt here.

It remains to add that only in the Canaries was there an aboriginal population, that of the Guanches, (*Cuscoy*, 1951, *Pellicer*, 1974, *Navarro*, 1983), who had a well-developed Neolithic culture. The pre-history of the Canary Islands (i.e. before the advent of Europeans), has therefore interested archaeologists, and caves, especially in such islands as Gran Canaria, Tenerife, La Palma, Gomera and Hierro, where pottery fragments, bones, wood instruments, etc. occur, have been studied via C-14 radiometric methods. (*Almagro*, 1970, *Guzman*, 1978, *Aguilar* et al, 1981). Dates thus obtained range up to ca. 2500 years B.C., it being assumed that before then, the archipelago was uninhabited.

DISCUSSION

Of more modern workers, the views of *Hausen* (1955, 1958, 1959; 1962, 1969, 1971, 1973 and many other papers), *Fuster* et al (1968), and *Schmincke* (1968, 1971, 1973, 1976, 1976/77, 1979, 1982) have all, in general, conformed to the view that the Canaries are products of U. Palaeogene-Neogene vulcanism, and that in Fuerteventura at least, Mesozoic sedimentaries occur. But more recently, *Storetvedt* and co-workers (*Storetvedt* et al, 1978, 1979, 1980, 1983) have challenged these views, believing rather that we have two principal volcanic phases, one in the L. Cretaceous or earlier, the other in the Late Tertiary. *Schmincke* in particular maintains that in the archipelago, no rocks are older than M. Miocene — in Gran Canaria and Tenerife specifically.

Lanzarote and Fuerteventura are closest to Africa (the latter a mere 100 km away), and for long the question has vexed geologists whether the Canaries are related to this mainland, in what manner and when, and in more recent times, *Rothe & Schmincke* (1968) had no hesitation about associating the above two islands with Africa, hence of continental type. For many years, pre-volcanic sedimentaries had been known in Fuerteventura, later denied, then «re-discovered» by *Rothe* (1968), who postulated strata ranging in age from Liassic to Cenomanian-Turonian, yielding a thickness up to some 4000 m — later drastically reduced to ca. 1500 m by *Robertson & Stillman* (1979). To date, oldest volcanics isotopically dated on Fuerteventura are ca. 38 MY, no less the oldest dated volcanics in the archipelago. Neither the volcanics nor sedimentaries of Lanzarote have such relative greater ages, where perhaps Vindobonian calcareous sediments and L. Miocene volcanics radiometrically dated, represent oldest rocks. *Stillman* et al (1975) believed that in Fuerteventura most of the Basal Complex was emplaced during the mid-Tertiary, dykes ranging within 46-32 MY and unconformably separated from the Complex are the Basalt Series I-IV of *Fuster* et al (1968).

It was the opinion of *Storetvedt* et al (1979) that somewhat powerful secondary alteration affected all rocks older than Basalt Series I, taken to be pre-M. Miocene by *Fuster* et al. *Storetvedt* et al thought that the Complex was emplaced sometime in the U. Cretaceous, followed by an erosional unconformity, succeeded by the development of Basalt Series I. There followed a period of volcanic quiescence of some 50 MY, after which Basalt Series II of post-Pliocene age were erupted.

These authors were well aware that such an interpretation was at odds with the conventional K-Ar studies of *Rona & Nalwalk* (1970), *Abdel-Monem* et al (1971), *Grunau* et al (1975) and *Stillman* et al (1975), and, we would further add, with the views of *Schmincke* (1979). *Grunau* et al, e.g. believed that the 38 MY alkali-syenite age represents one of the presumed youngest intrusives; *Robertson & Bernoulli* (1982) claimed that the main phase of intrusion occurred within a period of some 22 MY, ranging from Late Eocene to Early Miocene, etc.

Storetvedt et al and *Storetvedt* (1980) pointed out the common difficulties associated with radiometric dating via conventional K-Ar methods (which keen advocates of isotopic studies too often gloss over) and we are thus left wondering just what are the ages of the volcanics the volcanic sequences and evolution — in other words, isotopic studies in Fuerteventura have not clarified matters.

Schmincke (1979) devoted some paragraphs as to whether the available K-Ar datings of Gran Canaria are reliable, whether the Shield-building Series are suitable for such analyses. As regards the former point, he accepted the almost ninety K-Ar determinations available and the one hundred and fifty values for the subaerial part of the islands, so that to him, the shield-building alkali basalts are the oldest volcanic phenomena, some 13.6 MY ago. Regarding the second matter, he placed more confidence in values obtained for rocks younger than 10 MY. *Storetvedt* et al, (1978) on the basis of palaeomagnetic data for Gran Canaria and Tenerife, believed there were two major volcanic phases, Mesozoic (likely Late Cretaceous) and U. Tertiary-Quaternary, and in 1980 and 1983, *Storetvedt* repeated his convictions of this, claiming that «*Schmincke*'s so-called biostratigraphic argument is difficult to follow in that the relevant Upper Cretaceous biostratigraphic sedimentary succession, within which our early volcanism should be detected, is actually missing at Site DSDP 397 (some odd 100 km S of Gran Canaria, RCM-T), early Miocene strata overlie Lower Cretaceous deposits».

It is thus manifest that for Gran Canaria, Fuerteventura and Tenerife especially, there is much debate going on, data for La Palma refer only to the top covering of lavas, rocks in the depth of the great Caldera de Taburiente are called «Basement» chiefly evidently because they occur low down in the rock sequence. In spite of the much greater isotopic work in the archipelago, whilst temporal refinements yield a precision not possible palaeontologically, yet relative ages of the islands had been known long before. *Lyell* (1855) for example, determined an U. Miocene age for the Las Palmas sedimentaries of Gran Canaria; *Gagel* (1910) recognized the relative oldness of now-known Mesozoic sediments in West-Central Fuerteventura (though his conjecture of Palaeozoic was grossly in error). The general sequences of volcanic stratigraphy for the islands had been creditably established many years before isotopic studies became available, and most age-sequence problems of past times have not yet been settled.

CAPE VERDE ARCHIPELAGO

Isotopic studies have been made on four of the fourteen principal islands — Brava, Ilheu Grande, S. Tiago and Maio. For the last-two we have geological monographs by *Serralheiro* (1970, 1976), two important papers on Maio by *Stillman* et al (1982) and *Mitchell* et al (1983), and for Bravo-Ilheu Grande, a modern geological map and explanatory report by *Machado* et al (1968). (Figs. 4, 5, Table IV) Brava samples come from where palagonites predominate, along with many basic and ultra-basic dykes, and it is probable that the former represent the oldest rocks on the island. *Bernard-Griffiths* et al (1975) determined an age of 5.9 MY for a phonolite, and 2.4 MY for a nephelinite, both from the NW coastal region.

On Ilheu Grande, largest (2 km^2) of a group of uninhabited islands some 7 km N of Brava, 4.3 MY was recorded for a Ne-syenite, the predo-

Tab. IV.-Radiometric Data, Cape Verde Archipelago.

Type Rock	Age MY	Authors	Region/Formation
BRAVA			
Phonolite	5.9 ± 0.1	B-Griffiths 1975	Alto do Sorno
Nephelinite	2.4 ± 0.2	ditto	Ponta do Padre
ILHÊU GRANDE			
Nephelinitic Syenite	4.3 ± 0.2	B-Griffiths 1975	?
S. TIAGO			
Theralite	10.3 ± 0.6	B-Griffiths 1975	14°09'N 23°34.2'W
Carbonatite Mica	9.8 ± 0.3	ditto	14°07.3'N 23°46.4'W
ditto	8.5 ± 0.7	ditto	15°08'N 23°46'W
Phonolite	7.1 ± 0.4	ditto	14°06.1'N 23°30.3'W
Basalt	4.70± 0.3	ditto	14°04.7'N 23°29.3'W
Limburgitic Basalt	4.15± 0.15	ditto	14°04.1'N 23°29.3'W
Basalt	4.10± 0.4	ditto	15°06'N 23°36'W
ditto	4.0 ± 0.5	ditto	15°02.3'N 23°29.5'W
			(Locations only given in Lats. & Longs. (corrected))
MAIO			
Pyroxenite R	21.1 ± 6.3	Grunau, 1975	Road Rib. João-Pilão, at Lomba da Vigia
Tephritic Phonolite S	14.0 ± 4.0	ditto	ditto
Porphyritic Tephrite Q	12.2 ± 2.4	ditto	Ribeira da Baia
Carbonatite Mica P	10.3 ± 0.5	B-Griffiths 1975	Monte Branco
29A Basalt	157 ± 4.0	Mitchell, 1983	Coruja Fm
29B Mugearite	99.8 ± 2.2	ditto	ditto
29C 01 Basalt	73.2 ± 1.2	ditto	ditto
7 Pill. Lava	62.1 ± 0.9	ditto	Batalha Fm
8 ditto	53.4 ± 3.3	ditto	ditto
9 ditto	47.3 ± 1.3	ditto	ditto
6 ditto	43.1 ± 0.9	ditto	ditto
10 ditto	40.1 ± 1.4	ditto	ditto
31 Alk Gabbro	19.3 ± 0.6	ditto	Central Intrusion Complex
5 Pill. Lava	18.6 ± 0.5	ditto	Batalha Fm
26 Ankaramite	15.4 ± 0.3	ditto	Sill-Dyke, Coruja Fm
4B Alk Lamprop	14.4 ± 0.5	ditto	Sill-Dyke, C. I. Complex
32 Essexite	14.3 ± 0.4	ditto	Central Intrusion Complex
4A Alk Lamprop	13.8 ± 0.2	ditto	Sill-Dyke, C. I. Complex
11 ditto	12.2 ± 0.2	ditto	Sill-Dyke, Batalha Fm
27 Mugearite	11.4 ± 0.3	ditto	Sill-Dyke, C. I. Complex
30 Carbonatite	11.1 ± 0.2	ditto	ditto
13 Alk Lamprop	11.1 ± 0.3	ditto	Sill-Dyke, Batalha Fm
25 Biot from Essexite	11.1 ± 0.8	ditto	Central Intrusion Complex
3B Alk Lamprop	11.0 ± 0.3	ditto	Sill-Dyke, Carqueijo Fm
14 Basanite	10.9 ± 0.4	ditto	Sill-Dyke, C. I. Complex
3A Alk Lamprop	10.8 ± 1.1	ditto	Sill-Dyke, Carqueijo Fm
12 Alk Lamprop	10.8 ± 0.2	ditto	Sill-Dyke, Batalha Fm

Tab. IV. (Cont. 1)

28 Biot from Ankaramite	10.0 ± 0.4	ditto	Sill-Dyke, C. I. Complex
2 Basanite	9.9 ± 0.2	ditto	Sill-Dyke, Carqueijo Fm
17 Ankaramite	9.8 ± 0.4	ditto	Casa Velha Fm
1B Basanite	9.3 ± 0.2	ditto	Sill-Dyke, Morro Fm
1A Basanite	9.2 ± 0.5	ditto	Sill-Dyke, Morro Fm
24 Ijolite	9.2 ± 0.2	ditto	Central Intrusion Complex
15 Basanite	9.1 ± 0.2	ditto	Sill-Dyke, Batalha Fm
16 Ankaramite	9.0 ± 0.2	ditto	Sill-Dyke, Morro Fm
22 Neph. Syenite	8.6 ± 0.2	ditto	Central Intrusion Complex
23 Essexite	8.2 ± 0.2	ditto	ditto
1C Alk Lamprop	8.1 ± 0.6	ditto	Sill-Dyke, Morro Fm
18 01 Melilite	7.3 ± 0.2	ditto	Malhada Pedra Fm
21 Ankaramite	6.9 ± 0.2	ditto	Monte Sto. António
20 Ankaramite	6.7 ± 0.2	ditto	Base of Monte Penoso
19 01 Melilite	6.5 ± 0.6	ditto	Malhada Pedra Fm

minant rocks here and well represented in southern Brava, both occurrences being termed nephelinitic syenites by *Machado* et al.

The oldest radiometric age recorded for S. Tiago by *Bernard-Griffiths* et al is 10.3 MY for a theralite from the Pico de Antonio Complex. (It should be noted that for this island, the authors give all sample locations only in terms of latitude and longitude, and that five of the eight latitudes are incorrect — all the «14°S» should be «15°S»). For

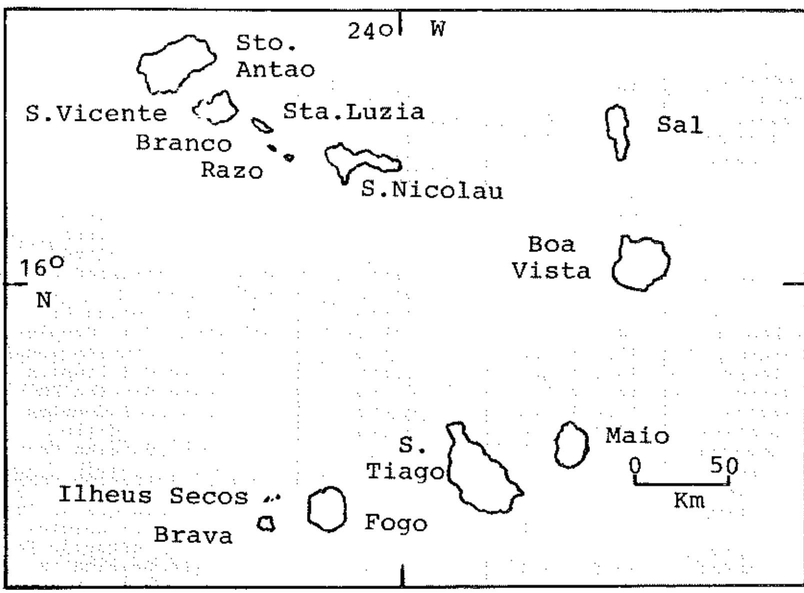

Fig. 4. — Cape Verde Archipelago.

micas within carbonatites in the Rib. da Barca area, ages of ca. 9 MY are given. These workers utilize the stratigraphic placings determined by *Serralheiro* (1976), but as mentioned below, *Serralheiro* has criticisms to offer here. (There is considerable confusion and uncertainty regarding how intimately *Bernard-Griffiths* et al and *Serralheiro* were aware of the studies of each other, further compounded by the fact that although *Serralheiro*'s publication bears the date of 1976, it did not appear in

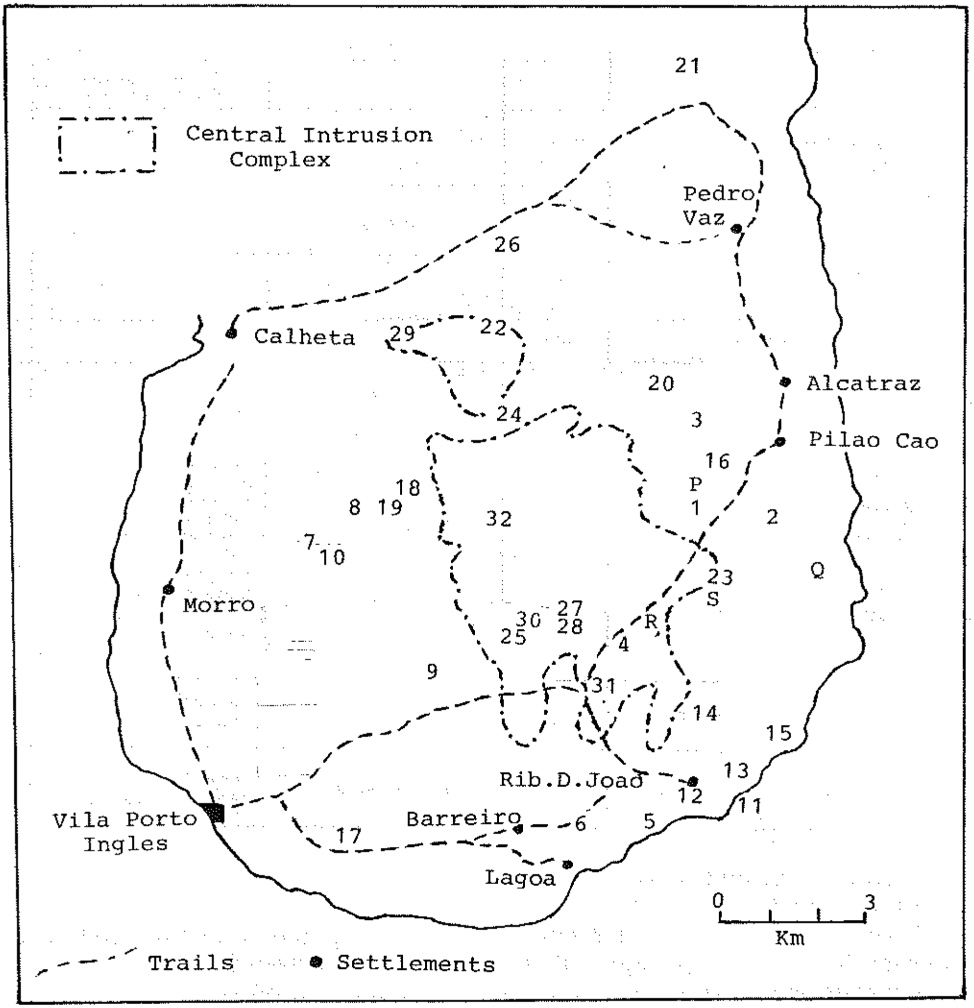

Fig. 5. – Radiometric Sample Locations in Maio of Bernard-Griffiths et al (1975), Grunau et al (1975) and Mitchell et al (1983).

Tab. V. - Stratigraphic Chart, Maio, Cape Verde Islands.
(Modified after Stillman et al, 1982 and Mitchell et al, 1983)

PERIOD/ EPOCH		FORMATION	MY	IGNEOUS	SEDIMENTARY
Pleistocene?					Beach dune scree, Beach and dune Calcarenites
Neogene		Penoso	7	Lavas, Tuffs	
Neogene					Interfluvial Conglomerates
Neogene		Malhada / Pedra (Central Intrusive Complex)	7-9	Mela-Nephelinites Flows	
Neogene		Pedro Vaz (Central Intrusive Complex)	11-12	Tuffs	Fluvial Conglomerates
Neogene		Casas Velhas (Central Intrusive Complex)	20	Hyaloclastics, Pyroxenites, Essexites, Syenites, Alk-Basalt Sills and Dykes	
Palaeogene					Erosion and/or Non-Deposition
Cretaceous	Senonian Turonian	Coruja		Pyroclastics	Conglomerates, Limestones
Cretaceous	Cenomanian Albian	Carqueijo			Shales, Muds, Limestones, Calciturbidites, Beach Conglomerate
Cretaceous		**Morro**			Pelagic Limestones Chert Nodules
Jurassic		Batalha	130? 155?	Pillow Lavas	Metalliferous (Fe) Sediments

print until 1978, and conversely, the former author's paper only appeared in print in 1976).

Maio has long been recognized as having the greatest geological interest in the archipelago. Initial stimulus stemmed from palaeontological-stratigraphical debates, and later, interests centred rather on igneous-tectonic problems. As long ago as 1913, *Hennig* had cautiously suggested (his caution was later overlooked by others) the presence of U. Jurassic limestones, from which originated long and heated arguments as to whether or not Jurassic (essentially Malm) or Neocomian represented the oldest sedimentaries. Now we have a total of forty-two radiometric datings from the island, and a more complete and refined stratigraphic table available. (Table V). Radiometric ages range from 157 to 6.5 MY, *Mitchell* et al correlating such with the stratigraphic table of *Stillman* et al. Three samples quoted by *Grunau* et al (1975) are placed in the Central Igneous Complex by *Mitchell* et al — though the latter quote slightly different values for the *Grunau* et al ages. *Bernard-Griffiths* et al quote a value of 10.3 MY for a carbonatite mica at Monte Branco (quoted as 10.6 MY by *Stillman* et al, occurring within the Morro Fm. of the latter authors.

The sketch maps of Maio by *Bebiano* (1932), maps by the author (*Mitchell-Thomé*, 1960), more detailed maps by *Serralheiro* (1970), *Stillman* et al (1982) and *Mitchell* et al (1983) illustrate clearly how increasing investigations on this island have elucidated a complexity not realized in earlier days.

Ranges in ages for the formations of *Stillman* et al are as follows: Batalha, 62.1-18.6 MY; Coruja, 157-73.2 MY; Central Igneous Complex, 21.6-8.2 MY; Neogene volcanics, 9.8-6.5 MY, with sills and dykes varying from 15.4 to 8.1 MY, which transect the Batalha, Carqueijo, Coruja Formations and the Central Intrusion Complex.

DISCUSSION

For S. Tiago, *Serralheiro* (1976) was led to remark that the geochronological data of *Bernard-Griffiths* et al (1975) were much different from ages arrived at via palaeontological studies. This disagreement was of two types: (1) radiometric values were much younger for units than hitherto believed; (2) in several instance, some more recent formations have been determined to underly older ones, and in the structural-tectonic setting of the island, this is not possible. These anachronisms are doubtless due to important loss of radiogenic Argon (the above authors made K-Ar measurements). On the other hand, both *Serralheiro* and *Bernard-Griffiths* et al agreed that the Pico do Antonio Complex is chiefly of Pliocene age — as per isotopic results, 4.7-4.15 MY — and it is obvious that it is essentially because of the positions of sedimentaries within the volcanics which involve stratigraphic problems. (These latter authors considered the Miocene as extending from 25-5 MY). All previous geological studies of S. Tiago (admittedly few in number) have postulated a pre-Miocene age for the island, and *Bernard-Griffiths* et al follow *Serralheiro* in considering the Old Internal Eruptive Complex of such an age. Yet the former give three isotopic samples from here ranging in age from 10.3-8.5 MY ! These same workers, in conclusive remarks of their studies, stated that except for the Pico do Antonio Pliocene formations, their K-Ar measures are unrepresentative of times of volcanic emplacements.

«Ils marquent au contraire une étape dans la surrection tardive de ces îles, au cours du Pliocène, surrection qui a soustrait ces roches à l'action du flux de chaleur important...........».

Most certainly then there are confusions and paradoxes for S. Tiago, and the eight available isotopic samplings (agreed few indeed for an area of 991 km^2) have in no way clarified matters.

Matters are little improved as regards Maio. As per *Stillman* et al: «The oldest igneous rocks observed on the island are pillow lavas and associated hyaloclastics on which the uppermost Jurassic limestones of the Morro Fm. have been deposited» Such is the Batalha Fm, where *Mitchell* et al gave age ranges from 62-18 MY, i.e. from U. Cretaceous to M. Miocene. The Coruja Fm gave ages of 157-73 MY, comprising predominantly tuffs with interbeds of limestones, alternating with tuffs and agglomerates, and the «microfauna in the upper part of the unit suggests an U. Cretaceous (Turonian-Senonian) age (*Rigassi*, 1972)». *Mitchell* et al agree that in all likelihood Argon loss has occurred in the micas of the Batalha samples, probably in excess of 10%. Further, there is a wide profusion of dykes and sills within the Batalha Fm (ages 12-9 MY), no doubt leading to «local» thermal metamorphism of the rocks in question. Ar^{40}/Ar^{39} stepwise degassing analyses of two Batalha samples resulted in changes of the K-Ar datings from 54.4 MY to 113 ± 9 MY, and from 62.1 MY to 97 ± 17 MY — indeed pronounced adjustments, thus bringing these two samples within the L. Cretaceous instead of the Palaeocene.

The Coruja Fm, with dates varying from 157-73 MY, in turn has been labelled Turonian-Senonian by *Stillman* et al, within the 105-65 ± MY range. Similar stepwise degassing analyses of two Coruja samples altered the K-Ar dates to a range of 1019-39 MY and 663 ± 60-19 MY. *Mitchell* et al therefore concluded that: «These Ar^{40}/Ar^{39} spectra are in other respects inconclusive, and we are forced to concur with *Duncan* and *Jackson* (1977) that in the Basement Complex......» our best estimate of the sample age remains that derived from overlying sedimenta (Upper Jurassic)». (A pretty acknowledgment of Geochronology to Palaeontology!) We are also informed by *Mitchell* et al that thermal overprinting of older by younger episodes «is in some cases total», e.g. Basement Complex lavas by Central Igneous Complex. *Stillman* et al considered the Batalha and Morro limestones as being U. Jurassic, basing their conclusion largely on the findings of *Serralheiro* (1970) and *Rigassi* (1972), of more modern workers. Yet we must note that of earlier investigators, e.g. *Stahlecker* (1934), *Trauth* (1936, 1938), also *K. Staesche* (extensive personal communications received during the 1950's and 1960's, but unfortunately he has never published), believed that these calcareous sediments of Maio were not older than Neocomian, opinions arrived at via detailed laboratory palaeontological studies and stratigraphic studies in the field. In the field, the writer was privileged to accompany *Dr. Karl Staesche* of Stuttgart several times whose intimate acquaintance with the palaeontology and stratigraphy of the much-debated sedimentaries was most impressive, far greater than before or afterwards.

Storetvedt & Lovlie (1983) and *Storetvedt* (1983) believe that the pillow lavas of Maio are of U. Jurassic age, followed by the major phase of sheet intrusion in the M.-U. Cretaceous (Albanian?-Senonian) within the interval 90-70 MY. There then occurred volcanic quiescence lasting from ca. 70-50 MY (was the absence of the Palaeogene due to emergence, erosion, non-deposition and cessation of vulcanism, as *Furon* (1935) and *Bourcart* (1946) both postulated?), with rejuvenated vulcanism in the Miocene-Pliocene. Unusually young radiometric dates are believed to be due to «an almost complete age re-setting», e.g. U. Jurassic pillow lavas giving ages of only 62-18 MY. Such a phenomenon is, «in conjunction with the overprinted magnetization. This explanation is further supported by the fact that K-Ar results of pillow lavas underlying Upper Jurassic limestones only give Tertiary ages». And further, they support *Bernard-Griffiths* et al (1975) that «a major Ar-degassing must have affected the Middle-Upper Cretaceous volcanics of Maio».

When one compares the conventional K-Ar methods of radiometric analyses with the Ar^{40}/Ar^{39} stepwise degassing analyses for the Batalha and Coruja rocks, as well as dyke and sill rocks cutting the Morro, Carqueijo, Coruja formations and the Central Igneous Complex, one does indeed receive a nasty jolt, where, e.g. the Argon stepwise degassing methods yield ranges of 906 MY at least for the Batalha Fm, though K-Ar methods give values ranging only through 43 MY!

Mitchell et al are in general agreement with *Stillman* et al regarding the volcanic stratigraphy and evolution of Maio — though we must note that the same three authors contributed to both papers. And yet the former publication confesses to unknowns and lack of precise agreements. Obviously the advent of later vulcanism has trenchantly affected primary or earlier isotopic characteristics, and we must conclude that in spite of the worthy efforts made by the above authors on the rock ages and volcanic sequences of Maio, results are still blurred, still ambivalent interpretations are possible, that radiometric, palaeontological and stratigraphical presentations but increase the confusion, that many of the old problems still remain. Verily Maio continues to confound and confuse.

CONCLUSION

Table VI pigeon-holes the isotopic datings for Macaronesia within stratigraphic units and thus indicates the temporal nature of these archipelagos.

Geological studies have been in progress for about 175 years, likely beginning with *Bennet's* publication on Madeira in 1811. Fossil studies go back to investigations by *Darwin* when the «Beagle» called at the Cape Verde Islands in 1832. Radiometric studies date from 1967-68. In almost all instances, the sedimentary and volcanic stratigraphy, also evolution, had been quite well established before the advent of isotopic studies, the latter serving to «touch-up» the general pictures previously obtained.

Tab. VI.-Stratigraphic Tabulation of Radiometric Data for Macaronesia

Islands	No. Samples	Stratigraphy
	AZORES	
Flores	3	Pleistocene
Faial	4	Pleistocene
Pico	3	Holocene
Graciosa	3	Pleistocene
Terceira	8	Holocene-Pleistocene
S. Miguel	10	Holocene-L. Pliocene
Sta. Maria	6	L. Pliocene-U. Miocene
Formigas	2	L. Pliocene
	MADEIRA	
Madeira	8	Pleistocene-M. Pliocene
Porto Santo	8	Holocene-M. Miocene
	CANARIES	
Hierro	8	Holocene-M. Pliocene
La Palma	5	Holocene-Pleistocene
Gomera	10	L. Pliocene-Upper L. Miocene
Tenerife	27	Holocene-L. Miocene
Gran Canaria	102	Holocene-M. Miocene
Fuerteventura	22	Holocene-U. Eocene
Lanzarote	11	Pleistocene-Upper L. Miocene
	CAPE VERDE	
Brava	2	U. Pliocene-U. Miocene
Ilheu Grande	1	L. Pliocene
S. Tiago	8	L. Pliocene-U. Miocene
Maio	42	U. Miocene-U/M Jurassic

In the overall general scheme of things, one wonders if perhaps too much is made of the so-called «precision» attributable to radiometric work. By and large, whether some unit, sedimentary or volcanic, is 4 MY or 4.2 MY matters little, until we come to the later Quaternary, and here determinations within ranges of tens of thousands or thousands of years indeed are of value, geologically, archaeologically and historically.

Conflicts between isotopic, palaeomagnetic, stratigraphic and palaeontological data and summations are apparent for much of the islands. If stratigraphic and palaeontologic writings, of long ago even as of now, are liberally sprinkled with surmisals, conjectures, postulations, beliefs, contentions, «feelings», etc., then radiometric and palaeomagnetic publications are little better in this respect. In the latter, too often there is the glossing-over of awkward findings, resort to mental gymnastics to explain inconsistencies, too often there is the «slaying of a beautiful hypothesis by an ugly fact», as per *Huxley*, who no less was aware that «those who refuse to go beyond fact, rarely get as far as fact».

Radiometric work on rocks and minerals really only were taken up seriously in the post-World War II era. If we compare other geological and geophysical methods, etc. in early years with later greatly improved techniques, then surely we can hope for notable improvements in isotopic studies. (YET — even today the magnitudes of quakes on the Richter scale, which extends from 2.0 to 9.0, have an inherent error of no less than 1 unit. So much for instrumentation in this wondrous age!). By no means can we ignore that latter, yet we cannot delude ourselves that such offer the «open sesame» to all geochronological problems. For Macaronesia, we now have better temporal precision for rocks, units, episodes and evolutions, and the value of such is not to be under-rated.

As «companions of a mile», the thoughts and witticisms of great minds should ever accompany us, such as:

«Robinson Crusoe did not feel bound to conclude, from the single human footprint which he saw in the sand, that the maker of the impression had only one leg». T. H.Huxley.

«If a man will begin with certainties, he shall end in doubts; but if he will be content to begin with doubts, he shall end in certainties». Francis Bacon.

«A theory is a tool and not a creed». J J. Thomson.

«There is no harder scientific fact in the world than the fact that belief can be produced in practically unlimited quantity and intensity, without observation or reasoning, and even in defiance of both, by the simple desire to believe founded on a strong interest in believing». G. B. Shaw.

«My reputation grows with every failure». G. B. Shaw.

«A plurality of suffrages is no guarantee of truth where it is at all difficult of discovery». Descartes.

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ADDENDUM

Only after the MS was completed and dispatched did the writer receive a copy of a paper dealing with some more recent radiometric results by *Feraud* et al (1984) *. Data given are presented in the table below.

The age of the basement in Sta. Maria is taken to have formed between ca. 5.2 and 4.6 MY ago, and an unconformable pillow lava complex inter-stratified with fossiliferous calcarenites, an age of ca. 3.8 to 3.3 MY. However on a fossil basis, *Zbyszewski & Ferreira* (1962) claimed an age of Vindobonian for such calcarenites, etc. hence much older than 3.8 MY, and admit that the 3.3 MY determination is anomalously young — perhaps due to argon leakage from the glassy matrix. *Feraud* et al claim that their values for the Basement Complex are more consistent than those of 8.12 and 6.08 MY recorded by *Abdel-Monem* et al (1975).

Four dykes in the Pico Arieiro-Pico Ruivo region of Madeira yielded ages from 1.81 to 0.96 MY, and agree well with those reported by *Watkins & Abdel-Monem* (1971).

In Porto Santo, four new datings from three samples in the Ribeira de Dentro area range from 13.1 to 12.3 MY, and are said to have ages similar to those noted by *Schmincke & Weibel*, (Chemical Study of Rocks from Madeira, Porto Santo, São Miguel and Terceira (Azores), 1972, N. Jb. Miner. Abh., *117, 3,* 253-281, Stuttgart), though this publication records no radiometric data of their own.

From Gran Canaria, six new isotopic dates are given, in good agreement with the findings of *Lietz & Schmincke* (1975), and *McDougall & Schmincke* (1976-77).

* Feraud, G., Schmincke, H-U., Lietz, J., Gostaud, J., Pritchard, G. & Bleil, U.:
1984. New K-Ar Ages, Chemical Analyses and Magnetic Data of Rocks from the Islands of Santa Maria (Azores), Porto Santo and Madeira (Madeira Archipelago) and Gran Canaria (Canary Islands). *Arquipelago, Rev. Univ: dos Açores, 5,* 213-240, Ponta Delgada, Açores.

Table relating to addendum.

Rock Types	Formations	Age, MY.	Location
STA.MARIA			
Basalt flow	Young Basalts	3.20 ± 0.17	Top, Praia W, road section
Basalt pillow	Submar.Compl.	3.3 ± 0.3	Pta. Castelo lighthouse
Basalt flow	ditto	3.42 ± 0.10	N coast,Mte.Gerda,145m alt.
ditto	Young Basalts	3.52 ± 0.17	Top, Praia E;road section
ditto	ditto	3.53 ± 0.10	S coast,Sn.de Piedade,115m alt.
ditto	Submar.Compl.	3.53 ± 0.12	Praia,E,road section,175m alt.
Basalt piece in seds.	ditto	3.77 ± 0.45	Praia,W,road section,60m alt.
Basalt flow	Young Basalts	3.85 mean	Pta.Castelo lighthouse
Basalt pillow	Submar.Compl.	4.23 ± 0.10	S coast, Sn. de Piedade
Basalt dyke	Basement	4.6 ± 0.1	Rd.Seladas-Malbusca,180m W summit
Benmoreite dyke	Basement	4.8 ± 0.25	Praia W,road section,N end of village, 70m alt.
Basalt dyke	Basement	5.25 ± 0.16	Rd.Almegreira-Sto.Espírito, 300m WNW Fontinhas
Basalt flow	Basement	5.27 ± 0.15	W coast,at airfield,5m alt.
Basalt dyke	Basement	5.5 ± 1.2	Rd.Almegreira-Sto.Espírito, 50m W Malbusca cross-road.
MADEIRA			
Ol.Bas.dyke	P.Ruivo Fm.	0.96 ± 0.10	Path P.Areeiro to P.Ruivo,1750m alt
ditto	Basalt Compl.	1.23 ± 0.15	ditto, alt. ca 1600m
ditto	ditto	1.40 ± 0.11	ditto
ditto	ditto	1.81 ± 0.12	ditto
PORTO SANTO			
Hawaiite flow	Submar.Compl.	12.3 ± 0.4	Rib.Dentro-Barr.Feiteiras
Trachyte intrusion	ditto	12.5 ± 0.3 12.6 ± 0.3	Ribeira Dentro
Trach.dyke	ditto	13.1 ± 0.4	Rib.Dentro-Barr.Feiteiras
GRAN CANARIA			
Nephel.pillow	Post-Llanos Fm.	1.02 ± 0.08	La Isleta, W coast, 6m alt.
Nephel.dyke	Los Llanos Fm.	2.59 ± 0.14	Marteles Caldera slope M.Caldera
Nephel.intr.	ditto	2.88 ± 0.09	Mart.Cald.,W entrance to canyon
Basalt flow	R.Nublo Fm.	4.29 ± 0.10	St.Lucia,road to Temisas
Nephel.flow	Tableros Fm.	5.07 ± 0.10	S.Nicolas, Las Tabladas Terrace, 80m alt.
Basalt flow	Mogan Fm.	13.7 ± 0.2	M.Cedro,W side,580m alt.