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Outline of the Geology of the Cape Verde Archipelago

By Raoul C. Mitchell-Thomé, Luxembourg

With 4 Figures and 3 Tables

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Zusammenfassung

Der Kapverden-Archipel, insgesamt 4033 km² umfassend, liegt ca. 460 km WNW von Dakar, Westafrika. Nach Topographie, Relief und geomorphologischer Entwicklung lassen sich die Inseln auf zwei größere Gruppen verteilen, die einen Hinweis auf ihr Alter geben.

Die Inseln bestehen überwiegend aus Erstarrungsgesteinen. Aus basischen Ergußgesteinen und Tuffen sind gegen 83% der Gesamtfläche aufgebaut, während Sedimentgesteine etwa 9% bedecken. Erguß- und Tiefengesteine sind deutlich basischer Natur; die Inselgruppe bildet eine natron-alkalische petrographische Provinz mit einem Differentiationsverlauf ähnlich dem anderer atlantischer Vulkaninseln.

Gesteine, vielleicht des Malms, sicher des Neokoms, finden sich auf der Insel Maio; sie zeigen das steilste Einfallen und die größten Mächtigkeiten unter den Sedimentgesteinen. Kreide jünger als Alb, Paläogen und Neogen sind nur sporadisch vertreten; die Existenz von Sedimenten dieses Alters kann vielleicht überhaupt in Zweifel gezogen werden.

Fogo ist ein aktiver Vulkan; der letzte Ausbruch erfolgte 1951. Die in 1600 m Höhe gelegene Caldera mit 8 km Durchmesser, in der sich ein auf 2829 m ansteigender Innenkegel erhebt, wird auf das Einsinken eines großen zylindrischen Blocks zurückgeführt. Der Magmaherd dürfte in einer Tiefe von ca. 8 km liegen.

Die Entstehung des Archipels begann wahrscheinlich vor etwa 180 Millionen Jahren. Seine Geschichte weist eine ältere und eine jüngere vulkanische Periode auf, die letztere wahrscheinlich spät-neogenen Alters.

Abstract

The Cape Verde Archipelago, totalling 4033 km², lies some 460 km WNW from Dakar, West Africa. Topography, relief and geomorphologic development enable the islands to be placed into two major groups, indicative of their respective ages.

The islands are overwhelmingly of igneous constitution, with basic volcanics and pyroclastics comprising some 83% of the total area, and sedimentary rocks amounting to some 9%. Volcanics and plutonics are distinctly basic in character, the archipelago representing a soda-alkaline petrographic province, with a petrologic succession similar to that in other Atlantic islands.

Rocks perhaps as old as the Malm, most certainly Neocomian, are present in the island of Maio, and here are found the highest dips and greatest thicknesses of sedimentary rocks. Post-Aptian Cretaceous, Palaeogene and Neogene are only sporadically represented, and indeed it can be questioned wheter any sediments are of these ages.

Fogo is an active volcano, last erupting in 1951. The 8 km diameter caldera, at an elevation of 1600 m with an interior cone rising to 2829 m, is thought to have resulted from subsidence of a large cylindrical block, the "feeding" magma chamber lying at a depth of some 8 km.

The archipelago probably dates back some 180 m. y., with an older and younger volcanic episode, the latter probably of late Neogene times.

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Résumé

L'Archipel du Cap-Vert, qui se monte à 4033 km², se trouve à 460 km ONO de Dakar, l'Afrique Occidentale. La topographie, le relief et un développement géomorphologique nous permet à classer les îles en deux groupes principaux, indiquant leurs âges respectifs.

Les îles sont composées principalement des roches ignées. Les roches volcaniques basiques et les roches pyroclastiques comprendent environ 83% de la superficie totale, tandis que les roches sédimentaires n'en causent qu'environ 9%. Les roches volcaniques et les roches plutoniques sont d'un caractère distinctivement basiques, l'archipel représentant une province pétrographique soude-alcaline, avec une suite pétrologique semblable à celle des autres îles atlantiques.

Les roches, peut-être aussi vieilles que le Malm, mais certainement de l'âge Néocomien, sont présentes dans l'île de Maio, et ici se trouvent les plus hautes plongées et l'épaisseur maximum des roches sédimentaires. Le Crétacé post-Aptien, le Paléogène et le Néogène ne sont représentés que sporadiquement et même on n'est pas certain s'il y a des sédiments de ces âges.

Fogo est un volcan actif, ayant fait sa dernière éruption en 1951. La caldéra, située à une hauteur de 1600 m, avec un diamètre de 8 km, et dans laquelle s'élève un cône intérieur d'une hauteur de 2829 m, est probablement le résultat de l'affaissement d'un grand bloc cylindrique, la chambre magmatique « fournissante » située à une profondeur de 8 km.

La naissance de cet archipel remonte probablement à quelques 180 m. a. Son histoire montre une période volcanique ancienne et une période plus récente, celle-ci datant peut-être de l'époque néogène.

Краткое содержание

Архипелаг Kapverden, охватывающий в общем 4033 км², лежит примерно на 460 км на WNW от Dakar, Западная Африка. По топографии, рельефу и геоморфологическому развитию эти острова можно разделить на две группы, указывающие на их возраст.

Острова составлены, гл. обр., изверженными породами. Примерно 83% общей поверхности построено из базических эффузивных пород и туффов; осадочные породы покрывают примерно 9%. Эффузивы и глубинные породы явно базической природы. Эта группа островов образует натриево-щелочную петрографическую провинцию с дифференциацией, похожей на таковую других вулканических островов Антлантики.

Породы возможного Мальма и несомненного Неокома находят на острове Maio. Они проявляют наиболее крутые уклоны и наибольшую мощность среди осадочных пород. Меловой период позднее Альба, Палеогена и Неогена встречаются редко. В существовании осадочных пород этого возраста можно даже сомневаться.

Fogo — это активный вулкан; его последнее извержение отмечали в 1951 г. Считают, что расположенная на высоте 1600 м кальдера с диаметром в 8 км, из которой поднимается внутренний конус на 2829 м, образовалась в результате опускания одного из больших цилиндрических блоков. Очаг магмы может залегать на глубине около 8 км.

Образование архипелага началось вероятно 180 миллионов лет тому назад. Его истории знает ранний и более поздний периоды вулканизма, последний, вероятнее всего, имеет позднe-неогеновый возраст.

Geographical background

The Portuguese Cape Verde Islands lie some 460 km WNW of Dakar, West Africa (Fig. 1). Fifteen islands are included, of which nine are inhabited. The total area of the archipelago is 4033 km². The population is 272,000.

On the basis of topography and relief, the islands can be divided into two major groups: those which are low, gentle relief, only scattered lower peaks (Maio, Boa Vista, Sal, Sta. Luzia), and those which attain greater elevations, show strong relief (Sto. Antao, S. Nicolau, S. Tiago, Fogo, Brava). S. Vicente occupies a somewhat intermediary position, both as regards topography and relief. On Fogo the towering active volcano of Pico rises 2829 m within 6 km of the sea on the east. The mountainous islands display a wild, rugged aspect, often with impressive cliffs, gorges, slopes can be remarkably steep. The low islands are characterized by expanses of low, gently rolling topography, dotted

Fig. 1. Islands of Macaronesia.

by steeper rises to individual peaks not above 436 m—725 m in the case of S. Vicente. The small areas of all the islands (Table 1) naturally means that neither valleys nor drainage basins are large. Only in NE Sto. Antao are there two short, permanent streams — everywhere else in the archipelago streams are intermittent or ephemeral.

The islands lie within KOPPEN's Dry Zone (BWh), being classed as having a hot, desert-type of climate. Because of its nearness, the intertropical front exerts a major influence in determining locations of pressure troughs. To the north is the semi-permanent sub-tropical anticyclonic area, from which emanate the quasi-permanent NE Trade Winds, the dominant winds affecting the area.

Altitude and disposition of the mountain ranges-peaks within each island exert climatic controls. Thus, for example, on high, windward slopes, annual rainfalls of 4000 mm may occur (in NE St. Antao), whereas on leeward slopes nearer sea level a mere 20 km away, half this amount of rain may fall in the same year. The latter half of the year forms the "rainy season", but throughout the greater part of the entire archipelago, rainfall is deficient for plant growth, and repeated "droughts" have plagued the islands.

Table 1. Geographic and Sedimentary Data, Cape Verde Islands.

Island	Area (km^2)	Max. Alt. (m)	Sedimentary Rocks			
			Max. Thick. (m)	Max. Dist. Coast. (m)	Max. Alt. (m)	Stratigraphy
Sto. Antao [1])	779	1979	2.0	500	4	Holocene, Pleistocene, Vindobonian?
S. Vicente [1])	227	725	2.5	1800	70	Holocene, Pleistocene, Palaeogene?
S. Nicolau [1])	343	1304	7.5	4000	250	Holocene, Pleistocene, Neogene, Palaeogene?, Senonian?, Malm?
Sta. Luzia	35	395	2.0	1200	50	Holocene, Vindobonian?
I. Branco	3	327	—	—	—	—
I. Razo	7	164	1.0	500	18	Holocene, Pleistocene?
Sal [1])	216	406	2.5	3200	105	Holocene, Pleistocene, Senonian? Valangian?
Boa Vista [1])	620	390	6.5	8400	175	Holocene, Valangian?
Maio [1])	269	436	435+	6300	265	Holocene, Pleistocene, Neogene, Palaeogene, Aptian, Barremian, Hauterivian, Valangian, Portlandian?
S. Tiago [1])	991	1392	34.0	1200	163	Holocene, Pleistocene, Neogene?
Fogo [1])	476	2829	1.3	2300	114	Holocene, Helvetian.
Brava [1])	64	976	3.6	1100	235	Holocene, Pleistocene?
Ilhens Secos: Grande	2	96	0.9 ?	400	52	Quaternary
Ilhens Secos: Carneiro	0.22	32	24.0 ?	200	32	Quaternary
Ilhens Secos: Cima	1.15	77	3.0 ?	200	47	Quaternary
Cape Verde Islands	4033	2829	435+	8400	265	Holocene to Neocomian or Portlandian?

[1]) = Inhabited.

Average annual temperatures are ca. 20° C, but above 1000 m the value is half this. Freezing temperatures are believed to occur on the summit of Pico during winter months.

Very high evaporation is typical everywhere at lower elevations, and this, combined with the erratic, small rainfall totals, means aridity is dominant. Only at higher elevations, say above 700 m, and in localities exposed to the rain-bearing winds, does the greenness of plant life relieve the monotonous barrenness. Sal, the driest and most barren of all the islands, has an average annual rainfall of 95 mm, with total annual evaporation as high as 3500 mm in some years.

Agriculture is the economic mainstay of the archipelago, but such can success-

fully be prosecuted only at somewhat higher elevations exposed to the NE Trades, or then via irrigation. Only in S. Tiago, Fogo and Sto. Antao are there forest stands, but some islands, e. g. Brava, have more extensive tree and brush growth in isolated places.

Praia, in S. Tiago, is the administrative capital and here is to be found the largest white Portuguese population. Mindelo, situated in the largest and best harbour (an old caldera breached by the sea) in S. Vicente, is the commercial capital, with ships of many flags — mostly cargo boats or tankers — calling here, for re-fuelling, taking on board fresh foods and even water — which is brought over from Sto. Antao in small local ships.

Geology

Darwin, during the epic voyage of the "Beagle", called at S. Tiago and in 1844 published some of his findings. These notes constitute the first geological account concerning the archipelago. We had to wait almost a hundred years, until 1932, before Bebiano's monograph appeared, the first systematic report on the geology of these islands. This reconnaissance study represented the best part of five years field investigations. All islands, inhabited or not, were visited by him except Fogo. It strikes one as strange that within such a period of time Bebiano never managed to land on Fogo and study this island well-known for its active vulcanism. Again we had to wait a considerable time for further detailed accounts, but within the past ten odd years there has been considerable geological activity by Portuguese geologists mostly. However it must be stated that geological knowledge of the islands is essentially reconnaissance in nature.

Like all islands and archipelagos of the Atlantic, the Falkland Islands excepted, the Cape Verde archipelago consists of volcanic islands. Bebiano remarked that basic volcanics, along with pyroclastics, constituted about 83% of the total area, phonolites and kindred rocks about 9%. In all islands then one is impressed by the overwhelming importance of igneous rocks.

Sedimentary rocks occur on all islands except possibly the tiny isle of Branco, but in every island they play a very subsidiary role volume-wise, though the stratigraphy is of distinct interest.

True metamorphics are indeed scarce, almost always of low-grade type. Though limestones are abundant, only incipient marmorization is to be noted.

The bibliography listed here, whilst not claiming to be exhaustive, does indeed indicate the best known and pertinent publications.

Geomorphology

The topographic and relief differences of the two major island groups is a reflexion of their age. The lower islands with milder relief — Maio, Boa Vista, probably Sal and Sta. Luzia — are older, have been subjected to erosional agencies for a greater duration of time. Those of greater elevation, more impressive relief — Sto. Antao, S. Vicente, S. Nicolau, S. Tiago, Brava — are considered younger in age, and in the case of Fogo, highest of all, here is a volcanic island still active.

Rivers, wind, the action of waves and currents have all been active in moulding the landscapes. Though permanent streams are all but lacking at

present in the archipelago, those of ephemeral nature (much more prevalent than intermittent streams) have, during the course of time, effected trenchant modifications of the landscapes. The depth, and in some instances the breadth no less, of canyon-like valleys, cutting through what appears to be volcanics no older than Late Neogene, testify to the powerful effects of these ephemeral streams which probably are active erosive agents for only a minute fraction of the average year. Especially in the older islands, the major rivers have developed relatively very broad valleys, usually choked with fluvial débris, such that the deeper parts of the valleys present a true braided appearance. Though one might expect that after the short, sudden rainfalls during the "rainy season" these "wadis" would become liable to flash-flooding for a few hours, whilst the writer was in the archipelago during the time of rains he never once saw anywhere wild flooding of the valleys, and observations by the local inhabitants seemed to confirm this.

Depositional forms are represented by dunes, sand sheets, river alluvium and extensive degradational landforms known as "achadas", occurring on many islands. These last-mentioned represent bevelled regions carrying a relatively thin veneer of loose rock material developed upon lava beds. As Assuncao (1968) remarked, they often form veritable structural platforms, at times grading into marine terraces. These "achadas" may extend from the coastlines up to elevations of some 550 m. On occasion the very gentle slopes terminate abruptly at the coast in pronounced cliffs, e. g. that upon which the capital, Praia, is built, and here one can observe the lava flow foundation.

Though vulcanism characterizes the archipelago, seldom are volcanic forms well preserved or imposing. Of first significance is the magnificent caldera, with its mighty walls, flat floor and central cone of Pico in Fogo. Equally impressive, though much smaller and lacking a central cone, is the caldera named Cha da Lagoa in NE Sto. Antao. Parasitic cones are excellently displayed on the slopes of Fogo and here too fresh lava flows can be observed on the eastern side of Pico extending down to sea level — areas of indescribable chaotic appearance.

The dominant NE Trade Winds blow with remarkable constancy, and usually these winds are blowing with a velocity of some 30 k.p.h. at least, especially on the windward sides of idlands. On the lower islands, dunes may be well developed in both area and height, and it would appear that all are "on the march".

The high islands can present wild, rocky coastlines, pounded incessantly by Atlantic waters which scarce ever are calm. The magnificent cliff scenery, say along the NE coast of Sto. Antao, bears witness to the powerful effects of marine erosion. The low islands have extensive gently sloping beaches, almost all composed of sand, again testifying to the pounding action of waves. Here and there on some islands marine abrasion platforms can be seen, but such are not common.

The peripheral "staircase" appearance of profiles on several islands bears witness to ancient shorelines developed during Quaternary times.

In the archipelago, erosion takes command, caused by one or other agent, and especially is this so in the high islands. The depositional phase as of now plays a minor role, and this is best exemplified in the low islands. The landscapes of the world are, geologically speaking, young in origin, and in the Cape

Verde archipelago this tenet is excellently demonstrated, for landforms of Mesozoic age are inconsequential, those of Quaternary age dominate the scene.

Igneous Rocks

Table 2 lists individual rock types which have been reported in the literature as occurring in the archipelago. In reviewing this table, we should bear in mind the following: (a) some islands, e. g. Fogo, Maio, S. Vicente, have been subjected

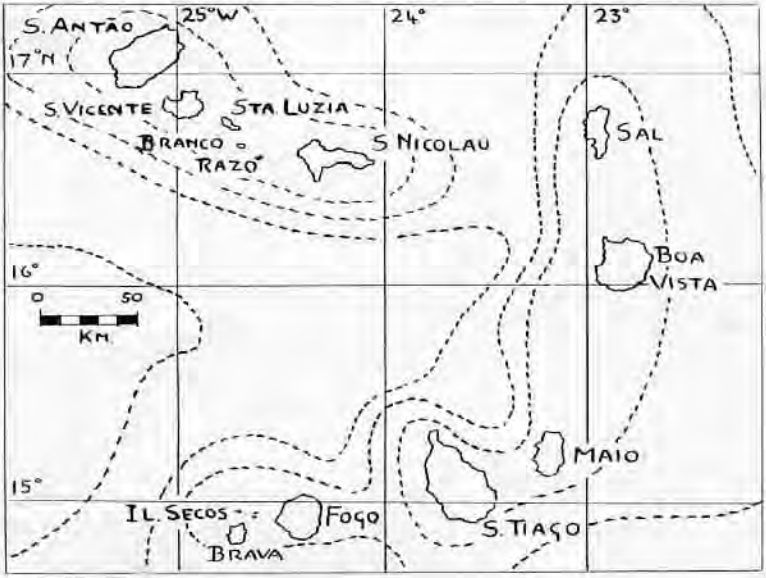

Fig. 2. The Cape Verde Archipelago (——— Isobaths at 1000 m intervals).

to more recent, detailed petrological investigations, whereas in other islands we still depend upon reconnaissance studies. (b) our knowledge of the occurrences of some igneous types in certain islands is based solely upon preliminary work such as that of Jesus (1932) and Bebiano (1932) and no further verifications have been made. (c) there is the age-old question of classification and nomenclature, e. g. Bebiano with his oceanites which Part (1950) would reject as the percentage of olivine is less than 20, hence he prefers the name olivine-basalt, etc. etc.

In spite of such precautionary remarks, it does seem possible to draw some significant conclusions concerning the igneous rocks of the islands.

Volcanics and plutonics invariably tend towards the basic end of the scale, i. e. visible quartz is all but unknown in the rocks. Not only are acidic rocks conspicuous by their absence, but intermediary rocks are distinctly minor. As remarked before, Bebiano believed that some 83% of the constituent rocks of the archipelago comprised basaltic-type lavas and pyroclastics, and no later worker has seen fit to offer serious objections against this figure which, even

Table 2. Igneous Rock Types present.

	S. Vicente	Sto. Antao	S. Nicolau	Sta. Luzia etc.	Sal	Boa Vista	Maio	S. Tiago	Fogo	Brava	Ilheus Secos
Analcitite	×						×			×	
Andesite	×	×	×	×							
Ankaramite							×				
Ankaratrite	×	×			×	×	×	×	×	×	
Augitite	×							×	×		
Basalt	×	×	×	×	×	×	×	×	×	×	×
Basanite	×	×					×	×	×	×	
Basanitoid	×						×		×		
Carbonatite							×		×	×	×
Crinanite	×										
Diorite	×	×	×	×	×		×	×			
Dolerite	×				×	×	×				
Essexite	×		×				×	×	×		
Etindite	×						×		×	×	
Gabbro	×				×		×				
Haüynite										×	
Hornblendite							×		×		
Ijolite	×	×					×		×	×	
Jacupiranguite	×						×				
Lamprophyre	×						×				
Leucitite							×	×	×	×	
Limburgite	×	×	×			×	×	×	×	×	
Manchurite									×		
Melilitite	×						×		×		
Melteigite	×	×					×		×	×	
Monchiquite	×	×					×	×			
Monzonite				×	×	×	×				
Nephelinite	×	×	×	×			×	×	×	×	
Obsidian						× ?					×
Palagonitite											
Phonolite	×	×	×	×	×	×	×	×	×	×	
Pyroxenite										×	
Sanidinite			×							×	
Shonkinite							×				×
Syenite	×	×		×	×	×	×	×		×	
Tachylyte						×					
Tahitite		×							×		
Tephrite		×	×						×	×	
Teschenite	×						×				
Theralite	×						×				
Tinguaite			×		×	×					
Trachyte		×	×				×				
Trachy-Andesite			×								
Trachy-Dolerite	×						×				
Vogesite							×				

although it should not be accepted as precise, does indeed give an approximate indication of the importance of such rock types.

An inspection made of the rock analyses reported by Part (op. cit.) — 49 in number, including some of Bebiano, Ermert and Lacroix — shows that only six thereof have a silica percentage higher than 55, of which a monzonite-syenite

from Boa Vista, with a value of 59.16% is the highest of any analysis recorded. Of 21 norms calculated by Part from these analyses, only two show the presence of quartz — a hornblende-trachyte from S. Nicolau with 8.40 and the same rock-type from Sto. Antao with 3.84 (Part stated however "... too much significance need not be attached to this ...", i. e. quartz in the norms of these two specimens.) Of 13 analyses of S. Vicente rocks reported by Assuncao and Canilho (1965), a feldspathoidal syenite is the richest in SiO_2 — 54.44%: of 43 analyses reported by Assuncao, Machado and Silva (1967) for Fogo, a basanitoid showed 44.30% silica, the highest recorded in these samples.

Burri (1960) considered 64 samples from the archipelago, classifying these into four series as follows:

Series I a	"Basaltic-Trachytic". $Si^{\circ} > 0.79$ al = fm 32 si 154
Series I b	"Basaltic-Phonolitic". $0.76 > Si^{\circ} > 0.65$ al = fm 29 si 126
Series II	Foidreich (Feldspathoidal). $0.63 > Si^{\circ} > 0.52$ al = fm 27 si 112
Series III	Lowest-silicified Melilite Rocks. $0.52 > Si^{\circ}$ al = fm ca. 25 (extrapolated) si ca. 100 (extrapolated).

Such divisions are clearly revealed in the Az°-Si° Rittmann and Q L M Niggli diagrams.

The chemical characteristics of these 64 samples are summarized in Table 3.

The igneous rocks of the Cape Verde archipelago indicate a typical soda-alkaline province, comparable to that of the neighbouring Canary Islands. However the Cape Verde rocks are distinguished from those of the other Marcaronesian islands by the extreme rarity of saturated types, the overwhelming dominance of under-saturated types. It has been the custom to add further that over-saturated types and glasses are completely absent in the Cape Verde islands. Bebiano had referred to exposures of obsidian at Monte Abrolhal in NE Boa Vista. Within some 2 km of this locality the writer observed some poorly-exposed, small, isolated outcrops of a black-brown rock, some chips showed a red-black mottled appearance, conchoidal fracture was characteristic. Field examination suggested obsidian. A sample sent for chemical analysis however yielded more critical results: the water content by weight was 8.56%, the silica weight content 54.40%, and the norm showed an excess of albite over orthoclase of only 4.85. There would thus be a tendency to refer to the specimen rather as a hydrotachylyte. But even so, this would be interesting, for no other glasses have been noted in the archipelago, and perhaps here we have a sample of a basaltic glass rather than a more acidic one, though the low S. G. of 2.34 is more suggestive of obsidian.

Table 3. Ranges in Chemical Characteristics of some

Series	si	al	fm	c	alk	k	mg	ti	p
I a	103.0	17.2	12.8	5.5	6.7	0.08	0.06	1.4	0.1
	216.6	40.2	46.5	30.7	38.2	0.47	0.59	6.1	0.5
I b	77.0	10.5	10.3	3.3	4.6	0.08	0.02	0.4	0.1
	191.2	42.3	56.1	33.4	44.8	0.36	0.65	8.3	1.2
II	64.1	10.1	13.9	6.1	5.3	0.11	0.22	0.4	0.1
	154.1	38.3	55.8	30.2	41.9	0.32	0.70	8.1	1.8
III	58.7	4.0	37.5	22.5	3.3	0.17	0.42	3.9	0.2
	86.6	19.0	70.2	34.5	18.4	0.30	0.75	6.3	1.4

Almeida (1961) classed the archipelago in his Hyperalkaline Series of the Atlantic suite, adopting the parameters al, fm, c, alk, qz, al-alk and c-(al-alk). Though "Atlantic" in petrologic character, the archipelago does represent an extreme position in the scale. Berthois (1950) determined an isofal value of 130 (Almeida quotes 128), but both these values should be increased, as per Assuncao (1968), because of a value of 108 for Fogo which was obtained subsequent to the above determinations. We would note, incidentally, that such a figure for Fogo would represent the extreme isofal yet determined for any Atlantic island.

The petrologic succession in the Cape Verde islands is similar not only to that in other Atlantic islands but also to that in the East African Rift area, and Burri (1960) draws analogies with the Young Tertiary-Quaternary vulcanism of the Rhenish Highlands. This succession (Assuncao, 1968) is: (i) basaltic lavas, (ii) phonolitic lavas and those strongly alkaline basic, (iii) later basaltic lavas marking a phase actually operative at present. This author claimed that the total absence of rock of calc-alkaline type within the archipelago argued against any assimilation of sialic material.

Sedimentary Rocks

Sediments and/or sedimentary rocks are present on all islands. Only in Branco are unconsolidated materials present, where sand dunes up to 100 m in height occur.

In general, sedimentary rocks tend to be restricted to peripheral areas, usually within some 2 km of the coasts. Maio and Boa Vista are exceptions in this respect, for large areas involve sedimentary rock exposures.

Sedimentary rocks are generally thin, commonly a matter of one or two metres at most. Maio is an exception, for here limestones total some 435 m thick. Many coastal cliff regions display interbedding of sedimentary rocks and lava flows and/or pyroclastics.

Generally dips are low, but in S. Nicolau they attein 47° and in Maio, 70°.

As regards lithology, limestones are of first importance, perhaps to the extent of some 90% of all sedimentary rocks seen. Several varities of limestones occur, but shelly-detrital types are commonest. Little alteration can be detected in the

ape Verde Igneous Rocks. (Based on Burri, 1960.)

qz	Si°	Az°	Q	L	M	α	λ	β	Series
— 6.2	0.79	0.51	24.4	31.2	8.7	0.02	0.00	— 0.03	I a
— 47.6	0.89	0.68	33.4	60.6	44.4	0.50	0.70	+ 0.18	
— 32.7	0.65	0.44	14.9	23.4	7.1	0.00	0.12	— 0.03	I b
— 84.4	0.76	0.68	26.6	68.6	61.5	0.56	0.41	+ 0.14	
— 52.6	0.52	0.39	8.1	24.7	9.3	0.00	0.21	— 0.64	II
— 102.5	0.63	0.61	19.9	70.8	67.2	0.40	0.51	— 0.33	
— 54.5	0.43	0.37	1.4	12.7	42.7	0.00	0.23	— 0.82	III
— 87.0	0.52	0.46	8.9	48.4	83.5	0.20	0.40	— 0.55	

limestones, but dolomitic varieties and, much rarer, ferruginous and bituminous types are found.

Conglomerates, of oligomictic type, of pebble, cobble and boulder size are next in importance, the ingredients being igneous and/or limestone fragments and authigenic siliceous cementing material. Calcarenites and tuffaceous sandstones represent the arenites, along with less common calcareous sandstones which often show good stratification and cross-bedding. Of argillaceous rocks, marls and calcareous clays predominate, showing little induration or fissility.

Large tracts of some islands, e.g. Boa Vista, have a hardpan or duricrust, usually a few centimetres thick, but on occasion up to nearly 2 m in thickness. Pedologically such regions are usually classed as reddish-brown soils, and frequently the calcareous crust forms horizon C at depths of ca. 15—30 cm. The real significance of the hardpan relates to water conditions, rendering large areas incapable of allowing infiltration of rainfall or dew to the thirsty ground.

Low-grade metamorphism, of thermal, optalic type, can be seen in some islands. Incipient marmorization is noted here and there, but true marbles are lacking. Crystalline limestones on the western coast of Fogo, eastern coast of Brava and in Ilheus Secos were once thought to be of sedimentary origin, but are now considered as carbonatites.

On all islands, sand dunes and sand sheets occur. In some, the former acquire unusual importance because of areal extent, volume and activity, tending to obliterate trails, airfields, gardens, etc. In Boa Vista, e.g. sand dunes and sand plains occupy an area of some 90 km². The groundwater potentialities of these dunes is great, and in this island it is possible that 3 million m³ of water is available annually.

Stratigraphy

Doelter (1882), Gagel (1910), Bergt (1913), Chevalier (1935), Furon (1935) and d'Orchymont (1936) all claimed an ancient "basal complex" of Precambrian and/or Palaeozoic age. (Later Furon changed his opinion.) Bebiano, whose field acquaintance with the archipelago can still not be surpassed by any individual, made no mention in his monograph of pre-Mesozoic rocks, a view which he con-

sistently held all his life. Further studies have all been in agreement that the islands likely date no older than Lower Cretaceous, perhaps Upper Jurassic.

FRIEDLANDER (1912) collected in the Ribeira do Morro, Maio, fractured specimens of aptychi, details being reported by HENNIG (1913). The same specimens and those collected and reported by STAHLECKER (1935) were further studied by TRAUTH (1936) and SOARES (1944—47), still further comments by SOARES (1952).

Down through the decades there has been considerable discussion, regarding the identification of the aptychi and further correlations with specimens in Germany (especially the Solenhofen area), as also the age assignements that should be given.

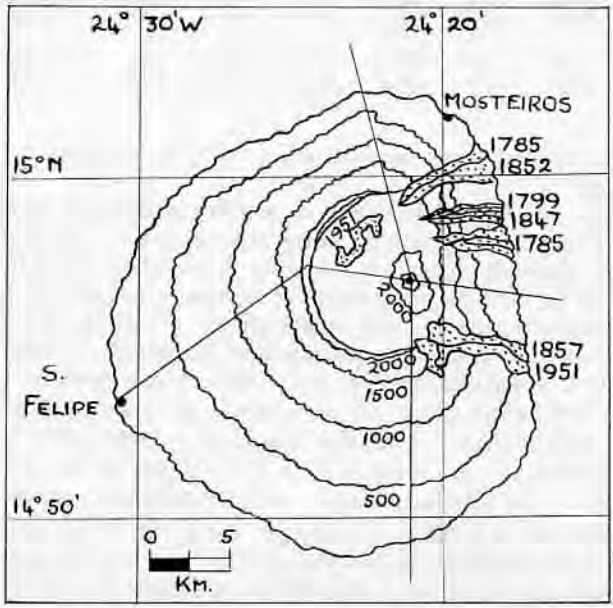

Fig. 3. Ilha do Fogo. (Contour interval 500 m. Flow occurrences after MACHADO, 1965.)

HENNIG specifically determined only one specimen, *Aptychus atlanticus n. sp.*, which differed only slightly in sculpturing from *Aptychus angulocostatus*. He also recognized a specimen closely corresponding to *Aptychus cf. euglyptus* OPPEL. Other specimens he referred to only as *Aptychus sp.* HENNIG concluded, with all reservations, that perhaps the fauna here in Maio was of the same age as the Upper Jurassic at, e. g. Solenhofen, although *Aptychus latus*, the commonest aptyphus occuring at Solenhofen, is missing in Maio.

STAHLECKER determined almost all his "very numerous" aptychi as *Aptychus angulocostatus*, only one specimen showing some similarity to HENNIG's *Aptychus altanticus* HENNIG. TRAUTH confirmed STAHLECKER's determination of *Lamellaptychus angulocostatus* and *Aptychus atlanticus* HENNIG he placed as *var. atlanticus* in the same species. To the unsculptured *Aptychus sp.* of HENNIG he gave the name *Laevilamellaptychus hennigi* TRAUTH (1936). TRAUTH considered that all these forms indicated a Neocomian age.

Soares (1946, 1944—47, 1948, 1952) consistently contended that *Laevilamellaptychus hennigi* Trauth (1936) should be assigned to the Dogger and Malm of Europe, the Tithonian of Argentina. He further stated that the aptychi collected in 1945 by Saldanha indicated an Upper Malm (Portlandian) age. As evidence of his contentions, Soares produced only new species or varieties, one of *Laevilamellaptychus*, two of *Lamellaptychus*, viz: *Laevilamellaptychus aff. xestus* Trauth *var. sousa-torresi* Soares, *Lamellaptychus saldanhai* Soares and *Lamel-*

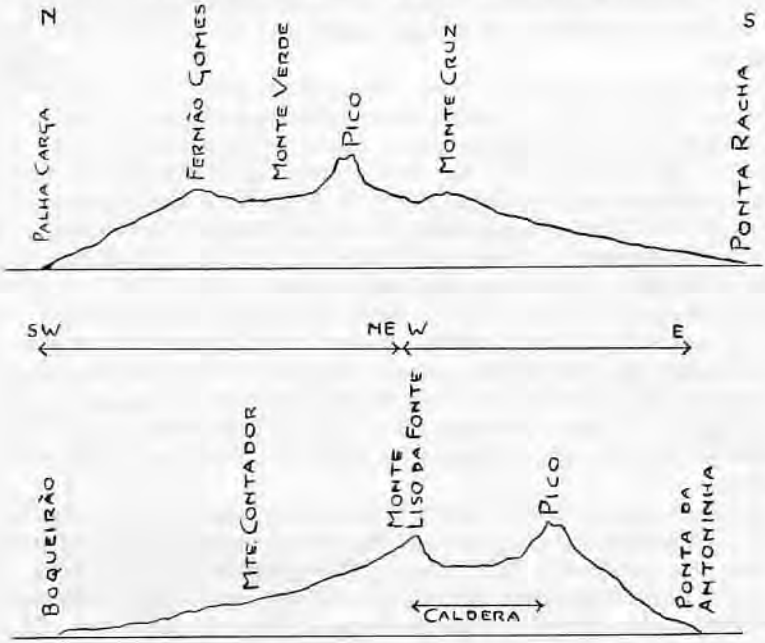

Fig. 4. Profiles of Ilha do Fogo. (H. S. 1 : 150,000; V.S. 1 : 100,000. After Torres and Soares, 1946.)

laptychus aff. saldanhai Soares *var. assuncaoi* Soares. It was the view of Soares that these new determinations, taking into account the facies characteristics of the rocks (limestones with flint nodules, showing styolites) indicated a Portlandian age. Soares was in correspondence with both Stahlecker and Trauth on the matter, and one gathers that Trauth evidently was prepared to accept a Malm age for the aptychi beds of Maio.

A keen student over a considerable number of years of the fauna and rocks of Maio especially has been Dr. Karl Staesche of Stuttgart. To the lowermost fossil horizon in the Rib. Morro, Maio, which was termed Horizon I by Stahlecker, this author had assigned a Neocomian age, and Trauth and Staesche were in agreement. In the lowermost beds beneath this horizon, neither Stahlecker nor Staesche found any recognizable fossils in the 50 m odd section — 20—30 m as per Stahlecker. The question might be raised as to whether the fossils studied by Soares might have come from these 50 m thick beds hitherto

regarded as non-fossiliferous limestones, occurring beneath the Neocomian of Horizon I. STAESCHE claims that even so, any of the arguments presented by SOARES in print are inadequate for establishing an Upper Jurassic age for these beds. STAESCHE searched diligently in these lowermost beds for fossils, and although aptychi were plentiful in higher horizons, not the least trace of a fossil was found. Material collected here was investigated by the electronic microscope and every diverse micropalaeontological technique failed to give any fossil results. In this lowermost 50 m section, no recognizable organic structure is evident, but in correspondence STAESCHE admits that the solution of the problem evades him.

The most recent worker on Maio, SERRALHEIRO (1968, 1970) considered the Rib. Morro beds as being "Undifferentiated Mesozoic (U. Juras? and L. Cret?)", whereas exposures in the eastern part of the island he placed in "U. Juras (Portlandian?)". He remarked that the two sedimentary occurrences, separated by volcanic outcrops, can be compared, on both lithological and palaeontological grounds, in which belief he is echoing the original idea of STAHLECKER. Although SERRALHEIRO discusses in some detail these old Maio beds, it is clear from his writings that still we cannot give definite pronouncements as to the age of these strata. STAHLECKER, TRAUTH and STAESCHE all believed that the oldest beds in Maio are Neocomian. FURON and SOARES are quite dogmatic in insisting on an Upper Jurassic age, but SOARES at least, who has written more on palaeontological matters, has not proven his case. STAESCHE's trenchant arguments — which unfortunately have not so far appeared in print — most certainly strike the non-specialist in matters palaeontological as highly significant and worthy of close attention.

In the same areas of Maio referred to above, STAHLECKER recognized the Neocomian — Valangian, Hauterivian and Barremian, as well as the Aptian. However one notes repeatedly that authors, in referring to Maio, refer only to the presence of "Undifferentiated Mesozoic" and hence we have no clear statement as to whether post-Aptian — Cretaceous may or may not occur here. On palaeontological grounds, STAHLECKER was of the opinion that post-Aptian was missing in the entire archipelago, whereas FURON (1935) thought post-Aptian was present but up to that time had not been recognized. SERRALHEIRO makes no mention of post-Aptian Mesozoic strata, in Maio at least. TORRES and SOARES (1946) thought that the relatively steeply-dipping marly limestones on Monte Focinho, S. Nicolau, were deposited during the Eocene, the process being completed by the Vindobonian. However in 1948 SOARES believed these beds to be either Senonian or then Lutetian. He also was of the opinion that azoic and/or metamorphosed limestones in S. Vicente, Sal, Maio, S. Tiago and Ilheus Secos belonged to the Senonian or then the Nummulitic. SOARES and FURON (1968) specifically mention Senonian strata, but such have not been suggested by others in the archipelago.

Thus, as was the case with the Upper Jurassic, the question of post-Aptian Mesozoic rocks occurring within the islands remains unsolved at this time.

TORRES and SOARES (op. cit.) referred to Eocene in S. Nicolau, S. Vicente, Sal, S. Tiago and Brava, Oligocene in S. Nicolau, Maio and Boa Vista. SERRALHEIRO recognized Palaeogene in Maio but attempted no further refinement. Most writers pass lightly over or then ignore mention of Palaeogene within the islands. The

apparent scepticism regarding the presence of Palaeogne, other than in Maio, may stem from a belief that a this time almost the entire archipelago was emergent, as first suggested by FURON (1935).

TORRES and SOARES indicated Neogene in almost every island, and they also attempted, more than others, to recognize stages. It would appear that to date the greatest number of Neogene faunal species occur in S. Nicolau, yet notwithstanding, the stratigraphical succession in this island is far from clear. To the above authors, the oldest Neogene is Vindobonian, and as Tortonian and Helvetian are indicated, Middle Miocene is assumed. Though the Burdigalian is generally thought to mark the initiation of the Miocene transgression, these writers believed that this began in the Helvetian in the archipelago.

In some micaceous and siliceous limestones in Fogo, near to the carbonatite occurrences, the writer collected *Olivia flammulata* LAMARCK *Arca (Senilia) senilis* LINNAEUS, *Chama gryphina* LAMARCK and *Certithium oemulum* SOWERBY, indicating likely Lower Helvetian. Neither before nor since has any reference been made in the literature to sedimentary rocks and fossils in this island.

The universality of Neogene in the archipelago, as per TORRES and SOARES, has tended to be treated with scepticism by others. LECOINTRE (1962, 1963), for example, specifically as regards Sal, and by inference, the entire archipelago, thought that many beds previously considered Miocene are in reality Quarternary, and in Sal, the Miocene, Pliocene and even old Quarternary are lacking. STAESCHE (personal communication) is most doubtful of Middle Miocene in Maio, prefers rather Upper Miocene or then Pliocene, whilst in Sal he was most dubious of Neogene.

That Neogene is present in some islands, e.g. Maio, S. Nicolau, Fogo, S. Tiago (?) is possibly the case, but the feeling today is that TORRES and SOARES overstated its importance and extent.

Pleistocene, mostly older, is common throughout the archipelago. Beds of Palaeosicilian, Neosicilian, Palaeotyrrhenian, Eutyrrhenian, Neotyrrhenian and Flandrian have been noted in Sal and Maio by LECOINTRE and SERRALHEIRO respectively.

Holocene, common throughout, is represented by active dunes. Marine terraces are frequent, as well as old beach Pleistocene deposits.

Vulcanology

The archipelago has had only one active volcano within historic times. The entire island of Fogo is the product of the activism of Pico, a truly magnificent volcanic form. An 8 km diameter caldera floor, at an elevation of 1600 m above sea level, has a crescentic-shaped wall (Bordeira) on the western side rising to a height of 2700 m. In the eastern half of the caldera rises the conic mass of Pico, with a 500 m diameter crater at the summit and walls rising 180 m above the base of the inner cone. Pico, 2829 m, is the second-highest elevation in all the Atlantic islands. (Pico del Teide, Teneriffe rises to 3707 m.)

The standard work treating of the history, geography and general geology of Fogo is that of RIBEIRA (1954, 2nd. edit. 1960); the works of ASSUNCAO (1954, 1955, 1967) and MACHADO (1962, 1965) deal with petrographic and mechanistic details.

The island was first settled about 1500 a.D., at which time it is believed vul-

canism was in force. More or less continuous activity occurred until the middle of the 18th. century, all of mild, summit-explosion, Strombolian type. Vulcanism ended abruptly about 1760, since when activity has been greatly reduced, both in frequency and violence. Lava outpourings took place in 1785, smaller ones in 1799, 1847, 1852, 1857, after which quiescence reigned until the impressive eruption of 1951, the last to date.

Breaching of the caldera rim occurs on the eastern side, with extensive flows mantling the steep slopes down to the sea. On the southern side, flows are much reduced in number, areal extent, thickness, and only a few reach the water's edge. The flows include basanites, limburgites and kindred rocks, augitites, basanitoids and manchurites. Studded within the caldera floor and the nephelinitic-scoriaceous outer slopes are some hundred parasitic cones, forming prominent small hills. Many of these cones have rectilinear alignments and most are to be classed as cinder cones.

In unravelling the volcanic history of Fogo, reference is made to two principal stages, adopting names from Vesuvius, viz. the earlier or "Somma" stage and the later or "Vesbio" stage.

The former is responsible for the overall structure of the island, where nephelinites, tephrites, basanites and augitites predominate, along with pyroclastics, often brecchoidal, comprising some 80% of the rocks exposed. On the steeper, upper, outer slopes and on the precipitous wall in the western part of the caldera, lavas are either alkaline, highly feldspathoidal, lacking olivine, or then habitually showing olivine, with freqent deficiency in feldspars. Nephelinites form the base of the lava outpourings. Pyroclastics — lapilli, cinders and tufa — alternate with lava flows. Many cinder cones dot the outer northern, western and southern slopes. Numerous dykes, quasi-vertical and up to 1000 m thick, form a complicated network within these "Somma" rocks. All the above events pre-date the formation of the caldera.

The "Vesbio" stage shows no outstanding differences in lava types, though there is less petrographic variation — nephelinites are much rarer, whereas basanites, olivine-basalts, ankaramites, limburgites and augitites are commoner. These lavas, which are posterior to the formation of the caldera, are poorer in alkalis and alumina, richer in magnesium than are "Somma" lavas. Cinder cones and intercalated cinder layers are also present. Lavas, pyroclastics and parasitic cones of the "Vesbio" stage all show a fresher appearance than those of the earlier stage. The last eruption of 1951 spread carpets of ash on the outer slopes throughout the island, as much as 20 cm thick, but such were rapidly worked-over by the soil and vegetation and today is indistinguishable.

The oldest part of Fogo is a carbonatite basement with associated alkaline dyke swarms. Such is to be seen in only three small outcrops near S. Felipe, the capital. This basement is considered of pre-Tertiary age.

According to MACHADO (1965), the caldera was formed as a result of subsidence of a large cylindrical block. The volume of the present caldera is approx. 24 km^3, and an explosion causing this great hollow would surely have shown itself in loose fragments littering the island slopes. Yet in fact, the volume of loose material is only ca. 4 km^3. The impressive caldera scarp (Bordeira), rising as much as 1100 m above the flat floor, thus represents a great circular fault. Subsidence is assumed to have been due to simple isostatic adjustment of the

central part of the large cone. Machado believed that the diameter of the caldera was of the same order as the depth of the magma chamber, i. e. about 8 km. This author also points out that in substantiation of a shallow locus for the magma chamber is the coincidence of Fogo vulcanicity with Earth tides, showing a periodicity of 18.6 years, tidal compressive forces being conceived as thrusting the magma upwards. Yet it must be noted that magmatic differentiation is absent, which would imply a quasi-permanent re-feeding of the magma chamber. To reconcile such apparent conflicting notions, perhaps the magma chamber is due to underground cauldron subsidence, where feeling is accomplished through ring structures, Earth tides acting only as triggers, the direct cause of eruptivity seemingly being actually unknown.

Structure-Tectonics

Few structures exhibited are of true tectonic origin. Such disturbances as are seen especially in the sedimentary rocks result from pseudo-tectonism — slumping and gliding — or then volcano-tectonic features imposed upon the rocks as a result of igneous emplacements. Sedimentation, lithification, diagenesis no less play important roles. Current-bedding is common, most seemingly resulting from wave action. Such structures of aeolian origin are rare, even in dunes.

Unconformities of significant proportions are few in number. As remarked already, in Maio is to be found the most important one, where Neogene, horizontally-bedded rocks rest on steeply-dipping Lower Cretaceous strata. These highly-dipping Mesozoic rocks of Maio call for special comment. Upwelling of viscous magmas, somewhat in diapiric fashion, is assumed to have been responsible for the fracturing and up-ending of these beds. The jostled Mesozoic blocks are now exposed on the eastern and western sides of a central igneous mass. As these limestones are indeed competent, one would assume that magmatic upwelling began relatively soon after deposition, i. e. before diagenesis set-in.

Faults of major proportions are singularly scarce within the islands. Minor slippages, jointing no less, is common enough, but such, as also the puckerings and minor foldings imposed upon the rocks, result from slumping, gliding, or are volcano-tectonic features imposed in consequence of igneous emplacement. Within the archipelago there are three more important faults: (a) a curvilinear N—S fault on the western side of Campo de Preguiça, S. Nicolau, outlined as a composite fault-scarp, extending for some 10 km and hading eastwards; (b) in Sto. Antao a likely fault, of reverse type, striking parallel to the northern coast for some 9 km, has created an upraised block, tilted to the N, between the Ribeira Grande valley to the S and the seacoast; (c) in SE Maio a major fault, trending NNW—SSE, with a throw of 450 m suggests, according to Serralheiro (1970), a complex diapiric structure with a "root" some 4000 m in depth. Gravimetric discontinuities would lead to postulating the presence beneath Maio of a rift developed by essexite intrusions.

For Maio, it must be admitted that Serralheiro does stress the importance of tectonism in the evolution of the island, but Maio differs in several important respects from the other islands, and the writer still conforms to the view that in the archipelago as a whole, evidences of structural disturbance are on a minor scale.

Much has been made by some writers of particular alignments of the islands

as also the isobaths. It has been well said: "Of the drawing of alignments there is no end". The subjective approach is so very obvious in such delineations, factual evidence usually scarce in the extreme, the imagination is allowed great scope to indulge in fanciful connexions upon which flimsy theories can be erected. As regards the Cape Verde archipelago, the writer has commented at greater length on this topic (1961, 1966), and will not labour the point here. Suffice it to say that considering the above matters, as also the reconnaissance nature of our geological knowledge of the area, lack of geophysical and oceanographic studies in the environment, it is presumptious, even fatuous, to launch into speculations of this sort, speculations of a tectonic magnitude which at times includes such vast and perplexing topics as the origin and evolution of the Atlantic Ocean, Continental Drift, etc. From such geological, topographic maps as are available, bathymetric charts of the vicinity, one is at liberty to draw alignments where one pleases, but is this Science? The writer will go no further than say that, on petrographic grounds, the archipelago shows some similarity with the East African Rift Zone.

Economic Geology

Other than salt extraction via evaporation of sea water, economic exploitation is non-existent. Some clays are used locally for the manufacture of crude ceramics. Guano deposits on Ilheus Secos are no longer exploited. The abundant sulphate of sodium on Fogo, of direct volcanic origin, does not enter into commerce. Some sands from the basic volcanics show high contents of ilmenite and magnetite, but are not worth developing commercially. Some springs qualify as of mineral type, but only one in Brava is exploited in a small, local way. The obtaining of adequate fresh water supplies has always been a serious problem in the islands. Repeated economic crises have occurred due to successive years of drought. Small, infrequent rainfalls, short, sharp showers, much sunshine, strong winds, high run-off and evaporation combine to render water problems most acute. Aggravating the matter is the continued rise in population, inducements to emigrate elsewhere within Portuguese territories having met with little success.

The pyroclastics, especially lapilli and ash beds, also sand dunes, offer the best underground water prospects. Groundwater potentialities within the inhabited islands are of the order of 236,000 m^3 daily, but yearly consumption is rising markedly, and within some fifteen years the projected population will be needing some 73% of all available supplies. It is indeed true that few islands in the world are as barren, as dry, and even in the vast well-known desert regions water difficulties are no more pressing for the nomads than for the settled populations of these islands.

Geological Evolution

The archipelago probably dates back some 180 m. y., and no vestige of a Palaeozoic and/or Precambrian basement is anywhere evident. Although intrusives are known on almost all islands, plutonics do not constitute the fundament. Bergt's (1913) concept of an intrusive basement (Tiefengesteine) presupposes that plutonics represented the initial igneous event, but such a view is not held today.

The Portlandian (?), Valangian and Hauterivan, with aptychi, of Maio represent the oldest rocks of the archipelago. Some authors have argued, e. g. Torres and Soares (1946), Teixeira (1950), that such limestones, clays and marls were formed at great depths, but Serralheiro (1970) would restrict only the clays to deeper marine environments, whereas the upper Maio limestones suggest a less deep milieu. Colom (1954 and personal communication) studied samples only from Maio, and whilst believing such to be majolica-type limestones and other pelagic-type sediments analagous to those of the Tethyan zone of the Mediterranean, refrained from giving any depth figures. (Teixeira for example, had mentioned a figure of 2000 m.)

The writer (1964) has criticized these pelagic views, and believes rather that these oldest sediments were deposited in neritic environments in epicontinental seas. Sea-bed oscillations, causing the outer parts of the infra-neritic zone to become part of the epibathyal zone are not excluded however. Present views are that the formation of the N. Atlantic began some 200 m. y. ago, the S. Atlantic perhaps 80—100 m. y. Consequent upon such an event of world magnitude, vertical movements of the sea bed, fracturing, dyke intrusions, submarine lava outpourings could all be envisaged as events sympathetic to this spreading of the ocean floors.

Part (1950) divided the igneous events of the archipelago into four stages: Stage I — earliest sills in Maio of Eocene (?) age; Stage II — 'Main basalt' series of early Middle Tertiary; Stage III — basalt, alkali-basalt, ashes, phonolite, intrusions of nepheline-syenite, nepheline-monzonite, essexite, of late Tertiary age; Stage IV — basalts, ashes, also formation of calcareous beaches, dune sands.

Assuncao (1968) recognized also four great phases of igneous activity. Phase I refers to the dykes and sills of basaltic and lamprophyric type which penetrate the Mesozoics of Maio, whose age can only be designated as having occurred during the Cretaceous-Lower Tertiary, but certainly posterior to these old sediments. These Cretaceous rocks of Maio underwent severe disturbances, as mentioned earlier. Resting in marked angular unconformable relation in Maio are horizontal marine, fossiliferous limestones of Miocene-Pliocene age, representing reef facies.

The presence of Mesozoic and Palaeogene on other islands of the archipelago is debatable. The case for Mesozoic is considerably more tenuous than for the Palaeogene. In general, the more modern view is that, Maio excepted, nowhere are there occurrences of sedimentary rocks older than Miocene. In Maio, Portlandian (?), Hauterivian, Barremian, Aptian and undifferentiated Palaeogene are recognized by Serralheiro (1970). The apparent absence of such older sediments in other islands could constitute evidence that before the Neogene the islands were non-existent, from which one would infer that vulcanism is not older than Neogene. Furon (1935), on the other hand, thought that during perhaps all of the Palaeogene, the islands were emergent, with the initiation of regression during the Danian, consequent upon transgression of Atlantic seas during the Albian-Senonian. He thus contended that because of emergence, sediments of Senonian-Oligocene age were absent throughout the archipelago, except of course in Maio. It should be noted, however, that in 1968 Furon was still listing Cretaceous and Eocene in S. Nicolau. In personal correspondence he now seems doubtful of Senonian at least in this island, and further draws

attention to his 3rd. edition in which he cites the presence of *Iberina lusitanica*, an Upper Jurassic species of Morocco, as present in S. Nicolau.

Assuncao (op. cit.) remarked that during all the Nummulitic and in the Burdigalian, the archipelago appears to have been totally emergent. As per Torres and Soares (1946), the Miocene transgression began in the Helvetian and continued till the Astian. During this transgressive period, deposition led to the development of slight stratal inclinations, i. e. initial dips. As these younger beds vary in age in various islands, and also because of gaps in the stratigraphic sequence, it is not possible to indicate precisely when the basaltic outpourings of Assuncao's Phase II took place. It was his opinion that the first manifestations occurred some time in the Palaeogene, for the Maio basaltic flows are overlain by strata likely of Miocene, presumably Vindobonian age.

Assuncao's Phase III is typified by alkaline-basaltic lavas, associated with phonolites and kindred rocks, for indeed a feature of this phase is the considerable rock variety — tahitites, melilitites, ankaratrites, etc., and also the intrusion of ijolites, melteigites. In several islands we recognize not only smaller extrusions but intrusions also, which are later than this basaltic Phase III episode. Assuncao surmised that such events did not commence before the Neogene.

Phase IV belongs to the Quaternary and continues to the present. Like the previous phase, it is typified by the emission of basaltic lavas — olivine-basalts, basanites, tephrites, nephelinites, limburgites, etc.

Quaternary times witnessed marked oscillations of the strands, with conglomerates occurring at various elevations above present sea level, often intercalated with sandstones. Berthois (1950), Lecointre (1963) and Serralheiro (1967, 1968) have commented upon ancient beaches, well preserved in some islands, e. g. S. Tiago, S. Vicente, Sto. Antao, Sal, Maio. In the last-mentioned, old beaches are found at 2—6 m, 8—12 m, 15—20 m, 30—40 m, 50—60 m and 80—100 m above present sea level, and are stratigraphically determined as representing the Flandrian, Neotyrrhenian, Eutyrrhenian, Palaeotyrrhenian, Neosicilian and Palaeosicilian respectively. The first five levels also occur in S. Tiago, whereas the first two and one associated with the Eu- and Palaeotyrrhenian are present in Sal. In S. Vicente the 2—6 m level has been detected. In Sto. Antao, sandstones lying 3—4 m above present sea level at Ponta do Sol are to be correlated with the Flandrian. It was the opinion of Assuncao (op. cit.) that although the archipelago is a structure of volcanic activity, all islands were not formed at the same time. The eastern, windward islands are older, more trenchantly eroded, topography is milder, younger volcanic evidences are lacking. These islands experienced his Phase I, and the first vulcanism likely dates from the end of the Mesozoic. During the Miocene, most of the islands were formed, but as there were significant sea level oscillations, this gave rise to deposition of Miocene and later marine sediments in coastal localities.

Isostatic adjustments probably were responsible for vertical movements in the archipelago and one might also ascribe movements in common with the submarine pedestals supporting the various islands. In whatever manner, the ascent of magma during the volcanic history was doubtless facilitated by sinking of the ocean floor, chiefly in the zone eastwards of the Mid-Atlantic Ridge. Bebiano was the first to invoke isostatic adjustments aimed at restoring equilibrium, but the writer feels that he and some later authors, have played rather 'fast and

loose' with this concept, that an appeal to isostatism smacks too much of a "Deus ex machina" approach. Be this as it may, but we should not lose sight of the role of eustatism during the Quaternary, evidenced by old beaches, now occurring as high as 100 m above present sea level.

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