STRUCTURAL FEATURES OF THE SEDIMENTARY ROCKS OF MACARONESIA

by
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ABSTRACT

The sediments within the five Maraconesian archipelagos of the Azores, Madeira, Selvagens, Canaries and Cape Verde are referred to. Lithology, structural features, outcrop areas, thicknesses, maximum dips, inland extents, highest elevations and stratigraphic ages are remarked upon.

The very uneven distribution of sedimentaries within the various archipelagos is noted, and a possible cause for the great thickness and older age of such in the Canaries and Cape Verde, as also their scarcity in the Azores, is given.

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RESUME

Dans cet ouvrage sont analysés les sédiments des cinq archipels de Macaronesie, les Açores, Madère, les Selvages, les Canaries et Cap Vert, par la lithologie et une des traits structuraux, de l'aire des affleurements, des épaisseurs, des pendages maximaux, des étendues vers l'intérieur, des altitudes les plus élevées et de l'age stratigraphique des roches.

La répartition très inégale des sédiments dans les divers archipels est commentée, et nous proposons une explication possible à la grande épaisseur et à l'ancienneté certaine des sédiments dans les îles des Canaries et de Cap Vert, et aussi à la rareté de telles roches dans les Açores.

RESUMO

No presente trabalho são referidos os sedimentos nos cinco arquipélagos da aMcaronésia: Açores, Madeira, Selvagens, Canárias e Cabo Verde.

A litologia, características estruturais, afloramentos, espessamentos, declives máximos, extensões interiores, elevações máximas e eras estratigráficas são referidas no trabalho.

É notada a distribuição muito irregular dos sedimentos nos vários arquipélagos e é fornecida uma causa possível para o maior espessamento e maior idade dos mesmos nas Canárias e Cabo Verde bem como para a sua escassez nos Açores.

INTRODUCTION

The occurrence of sedimentary rocks within small volcanic islands in an oceanic environment is a matter not of interest but of wonder. That in some instances such rocks may attain thicknesses of several hundred, even a thousand and more metres, show dips up to the vertical, outcrop over relatively large areas, date back some 200-250 MY — all this is remarkable when one considers how unstable, how dynamic, how trenchant the erosion shown in such islands.

The Macaronesian archipelagos, W of the coasts of Europe and Africa, are all of volcanic origin, volcanics, pyroclastics

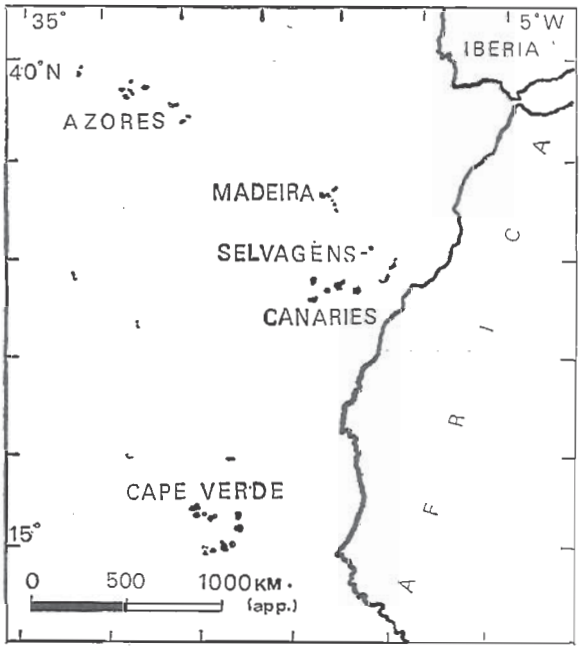

FIG. 1 — Macaronesia, Geographic Location.

preponderant (with some plutonic basal complexes), yet here sedimentaries outcrop, chiefly of calcareous type. The petrology, palaeontology, stratigraphy of these sediments are reported in many publications, though the sum total of sedimentary knowledge is small indeed, in fact, largely reconnaissance. Here we intend rather to comment upon the general geometry and structure of these rocks, treating specifically only of pre-Quaternary material.

In several publications, the writer (1960, 1964, 1972, 1974, 1976, 1979) has discussed overall aspects of such sedimentary occurrences. Table I, in succinct form, gives the basic information, differences in some figures quoted here compared with those in the above publications being due to subsequent data available in the literature of then further field studies.

Five archipelagos comprise Macaronesia, Azores, Madeira, Selvagens, Canaries and Cape Verde, extending between 15°-40° N and 13°-32° W, varying in distance from mainlands between 100 and 1900 km.

In the nine major islands, totalling 2344 km², sedimentaries are restricted to the extreme eastern one, Santa Maria, and the reef islets of Formigas.

Outcrops in the former are highly sinuous along all the coasts except in the W, and penetrate in tortuous manner up the valleys, occurring as narrow tortuous ribbons as seen on a geological map. Here, as elsewhere throughout Macaronesia,

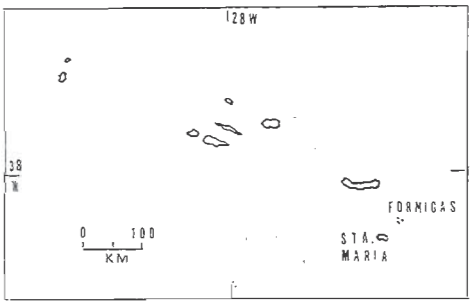

FIG. 2 — Azores Archipelago.

sedimentaries are intimately associated with volcanics and pyroclastics. Frequent intercalations of these three rock types may mean that in a section of say 30 m, sediments may together total no more than 4-5 m.

Polygenetic conglomerates invariably are thickest — up to 15 m — and limestones thinnest — usually not more tham 5-6 m thick. Fossil contents would indicate limestone-calcarenite formation in depths less than 100 m and mostly less than 40 m, with sharp boundaries against conglomerates, breccias, tuffs, flows etc. Occasionally calcarenites and finer conglomerates show crude graded and current bedding.

For almost all the Macaronesian islands where sedimentaries occur, the possible or probable subsurface extents thereof are mentioned in the literature, in terms vastly greater than actual outcrop areas, but as only the latter can be determined with some degree of accuracy, they alone are represented in Table I.

MAYER-EYMAR (1864) and AGOSTINHO (1937) both believed that the limestones and calcarenites probably underlay most of Santa Maria, having undergone drastic erosion, but were present beneath later lava outpourings, and indeed AGOSTINHO thought that sediments of similar age (Vondobonian) occurred at depth throughout the archipelago, being observed in Santa Maria only because of greater uplift here (A 981 m hole drilled in northern S. Miguel encountered only lavas and pyroclastics. (MUECKE et al., 1974). In Santa Maria, strata are inclined up to 30°, and tend to show a westward inclination, so that here at least, it may be that outcrop absence in the western part of the island is due to later coverings of lava flows.

The reef limestones of Fordmigas are strung out over a kilometre in a N-S direction, mere islets some of which are only exposed at low tide. The linear N-S trend is taken to represent a fissure through which basalts were erupted during the Vindobonian into these shelly fragmented limestones of similar age. Palaeontological data is available regarding these

limestones (ZBYSZEWSKI, 1962), CHAVES (1924) made general geological comments, but no further specific information on these limestones is available.

On Santa Maria, the marine Miocene beds have been uplifted to maximum heights of some 400 m, whilst in Formigas reef limestones have been observed to depths of several metres below low tide.

MADEIRA ARCHIPELAGO

Pre-Quaternary sediments outcrop on only two of the three island groups.

In Madeira proper there is one significant occurrence of limestones in the Ribeira S. Vicente area, in valley sides, in depressions which are old quarry sites, and as loose and

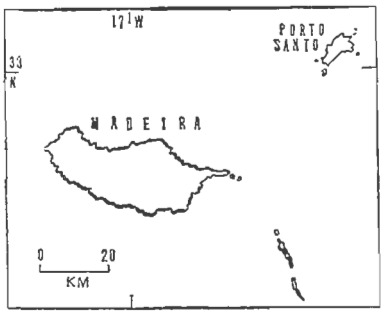

FIG. 3 — Madeira Archipelago.

scattered boulders. One or two writers, e.g. ACKERMANN (1909) have mentioned similar Vindobonian limestones in other localities, but such have not been generally substantiated. The fossiliferous beds have a massive appearance, with sandy-shaley partings, usually impregnated with granular ferruginous

material. Thicknesses of up to 12 m can be recognized (ACKERMANN'S supposed thicknesses of up to 40 m is accepted by no one), with dips up to 15°, and occurring as high as 425 m above sea level. Coralliferous limestones, neritic limestones comprising Melobesiae limestones, Tmphistegina-Amphiroa limestones and detrital limestones are all present. Mineralogically the limestones show little diversification, with quartz grains present in the detrital fractions. (ROMARIZ, 1971). Lignites, up to some 30 cm thick, scattered ash remains and comminuted fossil plant remains occur sporadically in the northern part of the island, at elevations up to 1400 m. Such at one time were of economic value to the islanders.

Porto Santo shows more lithological variety — fossiliferous and tuffaceous reef limestones, tuffaceous sandstones and calcarenites, coarse sands, argillaceous beds with siliceous nodules, and conglomerates. Their age is the same as the sediments of Madeira proper, vi. Vindobonian. They have a sporadic but relatively wide occurrence within the island, except along the NW sector. Similar strata are found outcropping in two of the off-shore islets.

Concretions, mostly oolites, are fairly common in the calcareous deposits, and biostromes are to be noted. Generally the limestones show better stratification than those of Madeira, bedding is less coarse, admixed material is less, suggestive of deposition in quieter, deeper waters. Dips also are generally greater than in Madeira, and up to 60° is present. These Miocene sedimentaries occur as high as some 350 m; and on occasion, up to 30 m thick. Whilst it apepars probable that such sediments extended throughout most of Porto Santo, we can say little about extents in Madeira proper, and indeed the unique occurrence of Miocene sediments in the latter is somewhat puzzling.

SELVAGENS ARCHIPELAGO

Comprising two islands, several islets and rocky outposts, the whole totalling some 4 km², this is the smallest of the Macaronesian archipelagos.

Selvagem Grande, in the central, higher flatter plateau, shows the presence of tuffaceous limestones, shelley tuffs, limestones, calcareous tuffs and calcareous-cemented conglo-

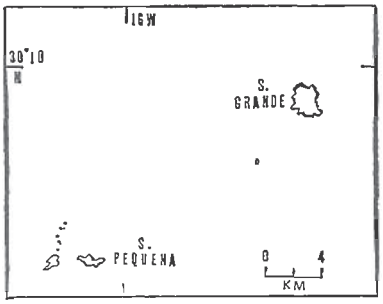

FIG. 4 — Selvagens Archipelago.

merates. Graded beding is quite a common feature, and in places calcarenitic material shows somewhat crude cross bedding, the latter of aeolian origin. Throughout the sedimentaries lie in marked disconformable relation to phonolites and tinguaites below and basaltic-type flows and explosive hyalotuffs above. Frequent also are calcarenite veins and dykes (the latter up to lm thick) cutting the three chief rock sequences. Measured sections by HONNOREZ (1966) show the relatively thin intercaltions of the sedimentaries within the volcanics, and aparently the former total only some 10 m maximum — usually coarse shelley tuffs and calcareous tuffs — with many intercalations to be measured rather in terms of centimetres, and

rudaceous deposits up to 7 m thick. Dips of up to 10° occur, though as slumping is quite a common feature, higher dips may be due to this, and in general the beds have a quasi-horizontal disposition.

Selvagem Pequena shows similar sedimentaries, with a somewhat greater development of calcarenites and calcareous tuffs and fewer limestones and rudites. Lithologically and stratigraphically (both sedimentary occurrences are Vindobonian) the occurrences in the two islands, 18 km distant and separated by depths up to 750 m, show close agreement, bathymetric contours suggesting that the two islands and islets, etc. were once all united into a NE-SW orientated ridge. Maximum elevations in the archipelago reach 153 m, with limestones outcopping as high as 80 m above present sea level. In both islands the sediments are believed to have a sub-aquatic origin, but aeolian action has played a large part in their present distribution.

CANARIES ARCHIPELAGO

In the seven major islands, pre-Quaternary sedimentaries are certain in four, may be present in two others.

In the extreme N of Lanzarote and in the neighbouring smaller island of Graciosa, essentially calcareous sediments

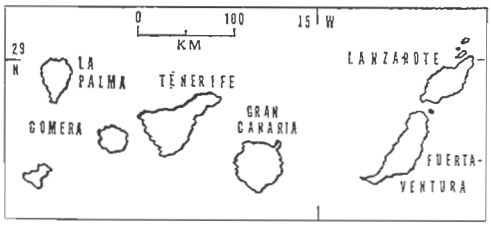

FIG. 5 — Canaries Archipelago.

outcrop, and in the tiny islet of Roque del Este, N of Graciosa and 11 km NNE from Lanzarote, marmorized limestone bombs in tuffaceous material are present. Marine and lacustrine fossiliferous limestones, calcareous sandstones, calcarenites containing terrestrial fossils and calcareous-cemented conglomerates and agglomerates can be recognized. For the most part, the limestones are pure, finegrained, partly marmorized; the calcareous sandstones (or oolitic limestones) show clastic stratification of imperfect type, ofter showing graded bedding, whereas the rudaceous rocks lack all stratification. The wavy appearance of the purer limestones, with very thin laminae of clayey material, probably represents oscillation ripple marks. Non-continuous outcrops of these sedimentaries seen along coastal sections and also inland, are well developed in the northern half of Lanzarote and in Graciosa. Faulting has caused the downthrow of blocks W and N of the main island, and subsequent to Miocene sedimentary deposition, extensive lava outpourings took place, thus burying the former, so that, recognition taken of faulting plus vulcanicity, probably means that at time of deposition, marine and terrestrial, these sedimentaries had a wide extent over the island, but just how extensive cannot be stated. Actual outcrops cover an area of some 7 km^2. Thicknesses of up to 30 m, with maximum dips ca. 15° can be gauged, such rocks occurring as high as 200 m above present sea level. Frequently loose and friable Quaternary sediments are in contact with older calcareous sandstones, calcarenites, etc., and hence distinction, in the absence of fossils, is not always clear, but the former have a much greater surficial extent throughout the island.

In Fuerteventura, Pliocene (?)-Quaternary sediments comprise partly marine, partly terrestrial foraminiferal limestones, sandy limestones, calcareous limestones with macrofossils and travertine limestones, the last-mentioned probably of Recent age. The marine-terrestrial limestones seem to outcrop only in coastal areas, intercalated with volcanics, dipping gently seaward but wedging-out inland. HAUSEN (1958) claimed they

could be observed, here and there, throughout almost the entire length of western-northern coasts, more sporadically along the leeward or easter-southern coasts. That much of this material is Quaternary is a likelihood, and indeed ROTHE (personal communication) stated that C-14 dating of some of these biocalcarenites suggested an age of 40,000-20,000 years. HAUSEN was consistently of the opinion that rudaceous and arenaceous terrestrial material is more likely Pliocene. The occurrence of *Lutraria lutraria* (?) and *Isocardia* in sandy beds may lend some substantiation to a Pliocene age. Purer, more compact, well-tratified limestones are more prevalent along the windward coasts, but occasionally they interfinger an dalternate with friable, sandy limestones containing terrestrial faunas, the latter showing crude graded bedding here and there. Sandy-silty limestones and calcarenites have a more extensive though sporadic occurrence along the leeward side of the island, with very few purer limestones outcropping. Further, these leeward deposits have been more readily attacked by both marine and aeolian erosion, with some excellent examples of aeolian cross-bedding. HAUSEN (1958) thought that sandy-silty limestones and calcareou sandstones were more widespread throughout the island than the purer marine limestones, and indeed suggested that their occurrence more or less coincides with the present area of the island, but the writer believes that the purer limestones are more widespread than Hausen supposed. Subsurface extents of all these sedimentaries cannot be ascertained, but the total area of outcrops is of the order of some 100 km^2. Dips throughout are gentle and generally seaward, maximum thickness of the order of 15 m, and attain elevations of some 250 m.

Older Mesozoic and Palaeogene beds, in no sense to be confused with the above sedimentaries, occur in W-C Fuerteventura, which in recent times have aroused much interest. (ROTHE, 1968, GRUNAU et al., 1975, ROBERTSON & STILLMAN, 1979a, 1979b, ROBERTSON & BERNOULLI, 1982). Long ago their greater age was recognized, though VON FRITSCH'S

(1867) and GAGEL'S (1910) suggestion of Palaeozoic has never been substantiated, whereas there is faunau proof of Mesozoic and Palaeogen Srata here are unusually thick — 2500 m as per GRUNAU et al.; in excess of 2200 m as per ROBERTSON & BERNOULLI — have undergone a high degree of disturbance, with tight foldings along with gentler foldings, faulting, offsetting, overthrusting of beds and structures striking W-E and NW-SE. For these graded detritals, which macroscopically show a rhytmic character which is far less evident when viewed microscopically, and which contain a relatively high percentage of quartz, FUSTER et al. (1968) postulated an outside source — Africa — whilst ROTHE (1968) pointed to lithologic-stratigraphic analogies with coastal sediments in Morocco. It has been suggested by ROBERTSON & BERNOULLI that the Tarfaya Basin siliciclastics of Morocco may be shallow marine-continental equivalents of the deep-water facies of Fuerteventura. As xenoliths, such sedimentaries (quartzites, phtanites, shales, marls, sandstones, limestones, etc.) also occur in neighbouring Lanzarote and in Gomera, the latter 300 km to the W, which led FUSTER et al. to suppose they originally extended throughout the archipelago. The strata probably represent flysch material, deposition being accomplished via turbidity currents in a probably pelagic environment. Dips are variable, but strata dipping 80° to vertical to the S and ca. 30° to the SW are commonest. The rocks in question are cut by innumerable joints and dyke networks are common. They lie within some 5 km of the W coast and at altitudes up to 265 m. Cretaceous, both Lower and Uupper, is recognized, but the presence of Malm and/or older Jurassic is open to question at this time.

Palaeogene rocks are more intimately associated with volcanics. The volcano-clastics were formed in relatively shallow waters, when the general uplift of the island hegan in Early Eocene times. These rocks have steep dips (ca. 70°) to the S, whereas the Lower-Middle Oligocene are only gently inclined (ca. 10-15°) in the same general direction. It is to be noted that the younger strata include a much greater percentage of

bioclastics, the faunal remains suggest either a guyot or then an offshore shoal bordering a volcanic structure. The Eeocene-Oligocene rocks total at least 100 m.

Sedimentaries in and around the capital of Las Palmas, Gran Canaria, have been know longer than any others in Macaronesia, VON BUCH (1825), being the first to report on such. Coarse, heterometric, terrestrial conglomerates and marine limestones predominate, the latter having aroused much interest because of fossil contents. The more recent studies of KLUG (1968) and NAVARRO et al. (1969) divide the sequence into three units, an upper psephitic of Upper Piedmont Horizon, a fine-grained limestone or Marine Horizon, and a lower psephitic or Lower Piedmont Horizon, with respective thicknesses of 100 m, 8 m and 40 m. On the more even, gently seaward sloping upland behind the capital, such sedimentaries extend over an area of some 50 km^2, reach an altitude of 350 m, whilst in the scarp behind Las Palmas, lower beds outcrop some 50 m above sea level. Maximum dips of 15° occur, inclination being to the ENE. It is contended that these sediments represent an old delta, now forming an erosion platform, planed-off by marine action during the Quaternary. Detritals show great variation as to size, the chaotic beds having the appearance of fanglomerates consistent with piedmon locations.

In the Arguineguin region in the S of Gran Canaria, conglomerates, agglomerates calcareously cemented, limestones and pozzulane deposits extend over some 20 km^2. They are present up to 5 km inland, occur at elevations up to 350 m, and show gentle dips southward. Both HAUSEN (1962) and FUSTER et al. (1968) believed that these deposits could be correlated with those of the Las Palmas area, both on lithologic and stratigraphic grounds. If indeed such a correlation holds — and for the Arguineguin area no fossil studies whatsoever have been made and lithologic similarities are far from striking — then these Neogene sedimentaries would once have extended over half the area of the present island, and indeed HAUSEN believed such deposits to occur in more central higher

areas. It would be of interest to determine if these Arguineguin sediments contain any fossils, and if so, what stratigraphic age assignments are possible.

In the extreme S of Tenerife, sedimentaries occur a few metres above high tide in the Punta Roja-El Medano region, where fossil remains of giant turtles and lizards (*Testudo burchardi* E. ABEL and *Lacerta goliath* MERTENS) occur in pozzulane deposits, which BRAVO (1953) took to be Pleistocene. Friable, cross-bedded sandstones, up to 10 m thick outcrop along the coast, probably a delta formation which has undergone extensive aeolian erosion to form wide, sandy beaches here. The pozzulane is massive, rather soft, with suggestions of current-bedding, in places inter-layered with the above sandstones which in turn rest on agglomerates. Pure pozzulane deposits attain a thickness of 20 m. If various occurrences of pumice-pumice tuffs are taken into account, then they, but far less so cross-bedded sandstones, have a considerable extent within the island and range widely stratigraphically. Though fossil finds have been reported within the pozzulanes, other than those of BRAVO (op. cit.) no other palaeontological details are forthcoming, and hence it is hazardous to assign an age, and what amount of both sandstones and pozzulanes might be pre-Quaternary is unknown as of now.

In the extreme N of Gomera island, sediments outcrop over an area of some 5 km^2. Excellent coastal sections occur and at the mouths of small valleys. These fine-grained detritals with Radiolaria are highly inclined, up to the vertical, striking N 20° E. These rocks are intercalated with a submarine volcanic series belonging to the Basal Complex, whose age is taken as M. Miocene. (CENDRERO, 1971). On the other hand, Cendrero did not exclude the idea that these might be Mesozoit deepwater rocks. Strata show graded bedding and lamination, but also massive, non-stratified outcrops occur, taken to indicate more turbulent depositional conditions. Field and laboratory studies of these rocks are non-existent.

Within the renowned caldera of Taburiente in La Palma, coarse detritals have long been known, and later were discovered present on the exterior S and SE sides thereof. Within the caldera, coarse conglomerates predominate, which are thought to form an ancient fanglomerate by HAUSEN (1969) or a marine-type of deposit by LYELL (1855) and HARTUNG (1962) because of included limestones which have not subsequetly been found by any worker. Towards the mouth of the caldera, which opens to the SW, sandstones become commoner, stratification being more perfect the nearer the present coast. These detritals extend from sea level to elevations of some 500 m on the extremely abrupt western scarp, and for some 5-6 km up the major valley (Barranco de las Angustias). HAUSEN (op. cit.)mentioned «some hundreds of metres of thickness» for this fanglomerate material, but landslide and rockfall material has become intermixed with the conglomerates, so that true thicknesses must be considerably less. On the SE exterior of the caldera, detritals occur over 2 km², outcropping at altitudes of 800-950 m and 12-13 km from the coast. All these La Palma detritals have the appearance of torrential deposits, with degree of stratification and fineness of grade increasing as the present coats is approached. The rocks in question are the ought to be pre-Quaternary, but there is absolutely no substantiation for a Miocene age (Vindobonian) as has sometimes been thought.

Gravitational mass movement material is Quaternary.

ROTHE (1967) mentioned the occurrence in SW Lanzarote of xenoliths of quartzites, sandstones and individual quartz grains within the oldest alkali-basalts. FUSTER et al. (1968), who strangely make no reference to this paper of ROTHE, elaborated further on such xenoliths in Lanzarote in their post-Vindobonian basalts. They mentioned specifically good graded quartzites, jaspers, phtanites, organic limestones whose faunal contents had not been studied (nor have they to this day), as well as plutonic xenoliths. These inclusions are believed to have been derived from the substratum — a Basal Complex which

at times has been considered as a correlative of that in Fuerteventura.

In Fuerteventura the Mesozoic graded detritals macroscopically show a rhythmic nature, far less prominent when viewed microscopically. Rocks in question here include quartzites, quartzitic breccias and metamorphic quartzite clastic grains.

In Gomera, quartzites and quartz grains are common in the sediments Graded bedding and lamination of alternating quartz and silt-clay bands is a common occurrence. (CENDRERO, 1970).

Such relative abundance of quartz and quartzitic material in the above three islands has aroused much interest, though to date all detailed studies are lacking. Both ROTHE & SCHMINCKE (1968) and FUSTER et al. (op. cit.) have indicated that such siliceous material must have had and outside continental source, «because even the most siliceous Canarian rocks (on Gran Canaria ...) carry little sand-sized modal quartz» (ROTHE & SCHMINCKE), and «the source area of these products was the African continent because there are no rocks in the Canary Islands capable of forming such types of clastic grains». (FUSTER et al.). The view is taken that such siliceous material must have a regional extent within the Canarian archipelago, at least from Lanzarote to Gomera, and the stratigraphic position (pre-Vindobonian and most probably pre-Neogene) suggests that sedimentation post-dated the emission of submarine lavas but predated subaerial lava effusions. For Fuerteventura alone, ROBERTSON & BERNOULLI (1982) postulated early Tertiary submarine volcanic outpourings into shallow waters, whereas L.-M. Oligocene bio- and volcaniclastics possibly indicate emergent sediment sources. Such conditions may apply to Lanzarote and Fuerteventura, the islands closest to the African mainland, but not to Gomera, well to the W, where environmental conditions were of much deeper water. There is an urgent need for detailed studies regarding these siliceous sedimentary occurrences, to enable us to ascertain if, and to what extent, the Canaries may have African affinities,

for though we have a plethora of theories, suppositions, «models», etc., factual evidences of Canaries-Africa relations are scant indeed, aven after the publication in 1982 of the volume treating of the NW African Continental Margin and study of deep bore-holes in the Canarian marine environment.

We may that it is of interest to note that HERNANDEZ-PACHECO & IBARROLA (1973) claimed that on the basis of geochemical variation trends of the igneous rocks, Lanzarote, Fuerteventura and Gomera show a marked geochemical similarity, different from that of the group Gran Canaria-Tenerife-La Palma, with Hierro occupying a special position.

CAPE VERDE ARCHIPELAGO

Pre-Quaternary sediments possibly outcrop in all twelve major islands and islets. However outcrop areas are small, thicknesses not great, dips in general gentle, Maio excepted. Throughout references include chiefly BEBIANO (1932), TORRES & SOARES (1946), SERRALHEIRO (1970, 1976, 1979) and the writer's personal observations.

In the W coastal area around Tarrafal in Santo Antão, sandy, compact, polygenetic limestones occur 3-4 m above sea level, with admixtires of phonolitic fragments and notable olivine

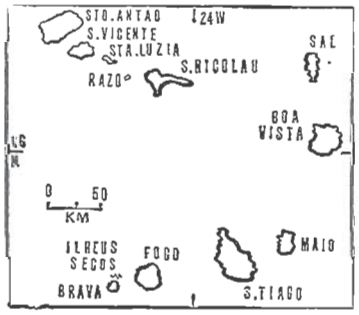

FIG. 6 — Cape Verde Archipelago.

grains. Stratification is crude, but there are suggestions of cross-bedding, with dips less than 4° towards the sea. The deposits appear to have formed under turbulent conditions in a littoral environment, resting on basalts and overlain by loose Quaternary material. In the extreme N of the island there is found a small marine abrasion platform, raised 3 m above the sea, at Ponta do Sol. The platform is formed of marine shell fragments of macrofossils, calcareously cemented to form a conglomerate. Bedding is absent. Such sediment sare taken to be Neogene. Though calcareous dunes extend quite far inland along parts of the southern coast, consolidated Neogene seems restricted to some 300 m of the W coast.

In S. Vicente sedimentaries are scarce, comprising sandy limestones, siliceous and calcareous sands and volcanic conglomerates with calcareous cementation and much sandy ingredients. The first mentioned are up to 1.5 m thick, dips ca. 3-5° more usually towards the SW, and are thought to be neogene. The metamorphosed and on occasion dolomitized limestones recognized by BEBIANO and others are now known to be carbonatites, forming dykes cutting andesitic lavas and exposed prominently above the surrounding terrain. Crystalline limestones of distinct ferruginous nature generally occur as lenses and thin layers within the volcanic conglomerates. Thickness is less than half a metre strikes and dips are difficult to judge, occurrences being small and sporadic. These rocks are not to be confused with carbonatites, as they are intimately associated with conglomerates whose volcanic and sandy ingredients contain marine fossils. (Vd. Maio infra.)

In Santa Luzia, sedimentaries similar to the sandy limestones of S. Vicente occur, but are consideraly more microbrecciated, and also volcanic admixed particles are commoner. Marine fossils are quite numerous which also indicate a Neogene age. In both island, heavy mineral components indicate a local origin for these neritic sediments. One clear case of torrential bedding has been observed in Santa Luzia, with horizontal laminae of silty clays sandwiched btween inclined coarser-

bedded sandy and even gravelly siliceous and coarse brecciated shelly material. Beds up to 1.5 m thick occur, inclined at angles up to 5°, usually to the W and SW, but torrential bedding shows dips up to 15°. On the near-by islet of Razo, softer outcrops of arenaceous limestones are seen, with here and there graded bedding. On occasion strata are strongly disturbed, likely due to slumping.

The sediments of S. Nicolau have yielded a rich number of fossil species though not necessarily a great number of fossils. The best known occurrences are at Monte Focinho and vicinity, where fossiliferous, marly, micro-crystalline limestones outcrop, up to 8 m thick at least, dipping generally to the SW at angles up to 28°, beds in question being interbedded beetween basalts. In several coastal areas, good exposures are found of similar rocks in similar basaltic environments, as also more conglomeratic, tuff-calcareous strata. On occasion, outcrops in cliff faces extend for hundreds of metres, especially along the S coast, beds maintaining almost the same altitude above the sea-level, though actually dipping slightly seaward. The broken, disorderly arrangement of fossil shells fragments and lack of stratification suggests that in many instances these essentially calcareous deposits resulted from strong wave action upon the loose fossil beds laid down on lava flows near the sea adge. Such events were invariably succeeded by fresh lavas, for sediments always occur within lava flows. The common tendency is for calcareous beds to show crystalline calcite, along with various degrees of milder metamorphism resulting from thermal processes associated with lava extrusions. In not a few instances, uplif of the islands has caused such interbedded shelly deposits to constitute true fossil beaches. The island sediments are now considered U. Miocene (SERRALHEIRO & UBALDO, 1979), though BEBIANO & SOARES (1952) thought Senonian might be present. The finding by MAYNC (1959) of a Portlandian foraminifera in limestones is now assessed as ship-ballast material, hence of no local significance. (SERRALHEIRO, 1976).

Loose material of dunal and alluvial nature have a considerable extent in the island of Sal, but pre-Quaternary, coherent rocks are more problematical. Consolidated beds comprising limestones and sandstones and gradations thereof, also fine-grained sandstones representing consolidated dunes, quasi-horizontal and up to 10 m thick, outcrop over ca. 40 km^2. The fine-grained sandstones and calcarenites, lacking fossils but showing good cross-bedding, display upraised and indented surfaces which appear to result from scouring wind action. Frequently these sandstones are intercalated with relatively thick, (up to 7 m) friable sandstones showing petrified rose-structures (grès tendre rosé) which contain abundant *Helix* specimens, this genus no longer living in the Sal area. Such sediments almost invariably have hard, calcareous crusts, enclosing smooth volcanic pebbles, succeeded in depth by solution-jointed limestones, the latter on occasion being a metre and more thick. These beds are considered to be Neogene, though a Palaeogene age is possible. On the other hand, they have likewise been thought to represent younger Quaternary. BERTHOIS (1950) mentioned Tertiary limestones having a total outcrop area of 41 km^2, but this is excessive, as it includes Recent calcarenite material. In the large island of Boa Vista, loose and coherent sedimentaries have a relatively wide extent, though the latter scarce exceed some 25 km^2 in outcrop area. Commonest rocks are rather friable sandy and silty limestones, with here and there intercalations of crystalline and saccharoidal limestones containing marine fossils, these latter type limestones being distinctly hard, compact, competent rocks. Of interest in these limestones is the frequent occurrence of subrounded grains (upt to 4 mm in diameter) of quartz admixed with calcite and volcanic grains. Some purer limestones contain quite large (oup to 1.5 cm diameter) rounded sulphur grains, presumed to have formed during a solfataric stage of neighbouring craters, the sulphurous gases being largely wind transported, precipitates becoming admixed with the limestones. Older, presumed Vindobonian rocks attain maximum thicknesses of

6-7 m, horizontally bedded though towards island peripheries a slight seaward dip can be detected.

Pre-Quaternary sediments were thought to be absent in the active volcanic island of Fogo, but such were discovered by the writer in 1960. In the Ribeira Sanha, a breccia comprising volcanics but also micaceous and siliceous limestones, the latter sometimes having a marmorized appearance, has a few poor, sporadic exposures in the stream bed, but neither extent, thickness nor dips could be judged. Fossils suggested a Vindobonian age. (MITCHELL-THOMÉ, 1964). Since the writer's visit to Fogo, carbonatites have been discovered some 3 km distant (MACHADO & ASSUNÇÃO, 1965), these rocks being originally described as metamorphosed limestones of gneissic texture by BEBIANO (1932).

Consolidated older sediments have a very sparing development in Brava with only small, isolated outcrops in the N and SW coastal areas, and in NE areas somewhat inland and at higher altitudes. Rocks include brecchoidal, crystalline, and sandy-silty fossiliferous limestones, some showing slight dolomitization and marmorization, as well as calcareous tuffs. In places, the limestones are intimately associated with breccias containing both volcanics and hard, pure limestones, all having quite high dips — up to 25°. In general,strata dip towards the S and SE, with limestone thicknesses up to 3.5 m. As in Fogo, some of BEBIANO's metamorphosed limestones have proven to be carbonatites (MACHADO et al., 1968). A Pliocene, perhaps even Miocene age gas been assigned to these rocks.

The uninhabited islets within sight of N Brava, known as Ilhéus Secos or Rombos, have exposures of pisolitic, detrital, corraline, tuffaceous, siliceous and ferruginous limestones. As per ROMARIZ (1970), detrital types are considered of marine littoral origin, corraline types of marine neritic environments, whilst the other types are of terrestrial character, the tuffaceous, siliceous and ferruginous varieties being related to mineral springs no longer existing. The metamorphosed limestones of some islets, as per BEBIANO, are now known to be

carbonatites. On Ilhéu Luís Carneiro, dips of 40° to the W and a thickness of 15 m for limestones can be observed, but elsewhere, both dips and thicknesses are greatly reduced — ca. 4-5° and 2-3 m respectively. These sedimentaries more clearly suggest a Vindobonian age.

The studies on S. Tiago by SERRALHEIRO (1976 but only apepaded in print 1978) and ALVES et al. (1979 but only printed in 1981) show a much wider and thicker occurrence of sedimentaries than earlier surmised. Principal rocks include conglomerates, breccias, limestones and calcarenites, with sands, clays, shales and marls being minor. Lahars have a relatively wide occurrence — over 30 km^2 out of total sedimentary extent of 83 km^2. These last-mentioned rocks indicate distinctly pluvial conditions and consequent sliding en masse, with little or no vulcanism to impede erosion furnishing lahar material. The rudaceous and arenaceous-calcareous sediments are of greatest interest, as their faunal contents allow of straitgraphic dating — essentially Miocene, but perhaps partly Pliocene. Dyke penetration, mostly of basaltic type, is a common feature here, and also sandy-gravelly-clavey material often forms clastic dykes. Marine facies volcanic and sedimentary rocks occur peripherally to terrestrial facies, hence at lower elevations. Former sediments frequently indicate estuarine features, with crude delta structures, or then bedding may be very scarce, even absent. Cross-bedding is common here and there, but graded bedding is rare. Throughaut the sediments are intimately associated with volcanics, with disconformable relattions, intercalations, stringers, lenses, etc. Terrestrial rocks generally have a chaotic appearance, suggestive of torrential deposition during periods of short, scaterred but intense rainfalls, as happens at present, which have greatest erosive-dislodgment effects in the high, rugged interior. Particles, fragments, even of conglomerates, tend to have a sub-angular rather than rounded shape. Thicknesses and dips of sediments vary greatly, the former from ca. 1-3 m up to 100 m and more, the latter

from ca. 3-5° up to 50°, with commonest thicknesses of 3-10 m and dips perhaps 10° or so.

Geologically, Maio is the most interesting island, though otherwise quite the least interesting. Here occur the oldest dated sediments — Neocomian, perhaps Malm and even older (RIGASSI, 1975) believed to be the only Mesozoics in the archipelago — the greatest thicknesses (?) the most disturbed strata, dips up to vertical, and the greatest areal extents. Sedimenta are of two distinct ages, Mesozoic and Tertiary, but the former have always aroused greater interest because of their fossil contents and the palaeontological-tratigraphical debates arising therefrom. The older rocks include compect, hard limestones, often siliceous, incorporating many flint nodules, less compact, sandy and silty limestones, shaley limestones, marly limestones, clays, shales and calcareous-cemented conglomerates including both volcanic and limestone ingredients. These U. Jurassic (?)-L. Cretaceous sediments outcrop over an area of 100 km^2 in the South-Central part of Maio, peripheral to a central complex of volcanics and plutonics. A deep-water depositional environment for these Mesozoics has been postulated by some — 2000 m by TEIXEIRA (1950), 2000-3000 m by KREJCI-GRAF (1965), 2500-4500 m by ROBERTSON & BERNOULLI (1982) ; others, e.g. SERRALHEIRO (1970) would claim that only the limestones suggest deeper (not specified) marine environments, whilst others still, e.g. COLON (1954) preferred to regard the limestones of majolica type without indicating depth of environment.

Tertiary strata have been considered as both Palaeogene and Neogene, but the work of CLEINTUAR & EALEY (1971) and RIGASSI (1975) has shown that beds once thought Palaeogene are now of M. Miocene age. On the NE border of the igneous central complex a distinctly conglomeratic sequence occurs, becoming more arenaceous and well-tratified towards the top, with minor clay-shale partings and lenses,volcanics and hard Eo-Cretaceous limestone pebbles also present. Dips vary between 30°-36° towards the NE, S and SW in the NE

sector of outcrops, as also in southern exposures and along the S coastal area where similar rocks also occur. This Pedro Vaz Conglomarate of at least 150 m thic[a]ness, has been assigned to the M.-U. Miocene by RIGASSI (1975), and is stratigraphically correlated with similar beds in both S. Tiago and S. Nicolau.

In some places, e.g. in the Ribeiro Morro area of the SW, friable, sandy and silty limestones, calcarenites and compact oolitic-type limestones occur, occasionally showing slumpage and minor pu-ckerings, not thicker than 10 m and dipping gently to the W-SW. In other localities, e.g. Barreiro, 3 m thick beds of such rocks rest in strong unconformable relation to highly-inclined compact Mesozoics, a 1 m thick conglomerate bed intervenin. These more friable beds are Neogene, likely U. Miocene-Pliocene.

SERRALHEIRO (1970) described what he termed « Depósito conglomerático-brechóide » underlying Quaternary chiefly in the NE and E parts of Maio. Major inredients are volcanics, but detrital limestones also occur, and further, there is much arenaceous and calcareous fine-grained loose material usually but also with siliceous and calcareous cementation. He specifically mentioned a thickness up to 4 m, but in some valleys these beds are 25 m thick at least. The same author likewise mentioned wide extents in S. Tiago of similar beds, beds up to 100 m thick in S. Vicente and somewhat vague reference to similar beds in Boa Vista, in all cases these rocks underlying Quaternary. In his 1976 publication, SERRALHEIRO appears to correlate such beds partly with his Orgaos Miocene Formation of S. Tiago and partly with the basal part of the Pico da Antónia Miocene-Pliocene Formation of the same island, and again mentions possible correlatives in S. Vicente and Boa Vista. The writer is of the view that a considerable proportion of such conglomeratic-breccioidal beds are Recent torrential deposits along with evidences of some graded bedding of very coarse type.

The Maio Mesozoics were taken to be 435 + m by BEBIANO (1932), 460 m by STAHLECKER (1934) whilst SERRALHEIRO

(1970) quotes a figure in excess of 1200 m. Tertiary sediments appear to be at least 175 m thick, so that a minimum figure of some 1400 m can be given. GRUNAU et al. (1975) quoted a composite thickness for the island sediments of 1500-2500 m, claiming that the sedimentary thickness near the island (based on seismic reflexion studies) was around 2000 m ROBERTSON (personal communication) seriously questions these figures, as there is significant and powerful thrust faulting in eastern Maio. As previously remarked, the Mesozoics can show dips up to vertical, but Tertiaries invariably are gently dipping on comparison.

CONCLUSION

Only rarely is our knowledge of sedimentaries in Macaronesia other than reconnaissance, and each new publication indicates how great amendments must be. Two points regarding these rocks deserve mention : (a) on stratigraphic geomorphologic bases, Fuerteventura, Lanzarote, Sal, Boa Vista and Maio are oldest, viz. islands closer to Africa : (b) the very uneven distribution of sedimentaries within the archipelagos, two out of ten islands in the Azores to twelve out of thirteen in Cape Verde. The original extents of sedimentaries within Macaronesia are hazardous to guess. As remarked earlier, some authors would postulate detritals throughout an E-W extent of 400 km in the Canaries ; Neogene in Cape Verde suggests a possible area of at least 100,000 km^2 ; in Madeira-Porto Santo, sediments have been presumed over an E-W distance of some 80 km, and *if* sedimentaries occur at depth W of Santa Maria-Formigas in the Azores, the sedimentary environment involved stretches some 650 km E-W by 300 km N-S. Compared to such relatively wide extents, large areas, pre-Quaternary rocks are seen as outcrops in only 4 % of Macaronesia today.

The very uneven distribution of sediments within Macaronesia raises questions. It would be risky to attribute greater

volumetric vulcanism in one archipelago rather than another — but duration of vulcanism does vary — such that greater burial of sediments takes place. It is questionable whether there has been more pronounced uplift or then more profound subsidence in one or other archipelago, though admitedly sediments are now seen at various altitudes in islands, ranging from 400 m in Santa Maria and Madeira (500 m in Hierro ?) to 4 m in Santo Antão. Whilst islands can be classed as low or high, archipelagos as a whole show little difference in relief, though individual islands do show such. On the other hand, certainly within historic and pre-historic times, there have been pronounced climatic changes, especially pluvial, from the present lush greenness of the Azores to the barren, tawny landscapes of Cape Verde. Palaeoclimatological studies are singularly lacking in these archipelagos but faunal, floral and lithologic investigations testify to climates much different from the present in past times. We may point out the frequency of torrential-slump deposits, lahars, massive, chaotic conglomerate breccia accumulations, most notable in Cape Verde, which surely suggest greater pluvial periods in former times.

In the Canaries and Cape Verde occur the presumed oldest sediments in Macaronesia. For these two archipelagos, KLERKX & PAEPE (1971) and FUSTER & CENDRERO (1973) postulated oceanic ridges during the Mesozoic, and ROBERTSON & BERNOULLI (1982) favour this concept also. The Mesozoic sediments of Canaries-Cape Verde have been thought to represent pelagic-hemipelagic depositional environments, though the writer (1964, 1972) has always favoured infra-neritic and epi-bathyal environments associated with epi-continental conditions. An oceanic ridge could well have created such a marine environment, and as regards Tertiary rocks, these are all shallow neritic deposits. It could be therefore that the ocean ridge(s) upon which Canaries-Cape Verde were erected, afforded more suitable sedimentary environments than other archipelagos, where much deeper water prevailed.

TABLE I

DATA REGARDING THE SEDIMENTARIES OF MACARONESIA

Archipelago	Island	Area (Km^2)	Max. Elev. (m)	PRE-QUATERNARY SEDIMENTARY ROCKS						
				Outcrop Area (Km^2)	Max. Thick. (m)	Max. Distance from Coast (Km)	Max. Alt. (m)	Max. Dips. (deg.)	Lithology	Age
AZORES	Santa Maria	97	587	11.5	25	2.8	400	30	Algal, Bryozoan & Foram Lsts., Calcirudites, Calcarenites, Cgls., Ssts., Tuffites.	Vindobonian-Pliocene
	Rocas Formigas	Ca. .05	14	?	?	?	?	?	Compact Corall. & Foram. Lsts., occasionally shelly.	Vindobonian
MADEIRA	Madeira	728	1862	?	12	2.5	425	15	Marmorized Corall. Lsts.. Arenites, Calcarenites.	Vindobonian
	Porto Santo	69	517	8	30	2	350	60	Reef & Sandy Lsts., Tuffaceou Ssts, Tuffs, Cgls.	Vindobonian-Pliocene
SELVAGENS	Selvagem Grande	Ca. 3.5	153	0.5	10	.75	80	10	Sandy & Dolom. Lsts., Calc. Ssts., Calcarenites, Calc.-cemented Cgls. & Aggloms.	Vindobonian
	Selvagem Pequena	Ca. .05	49	0.2	?	0.4	20	3	Sandy Lsts., Calcarenites, Ctlc. Tuffs.	Vindobonian
CANARIAS	Lanzarote	196	671	7	30	7	200	15	Marine & lacustrine Marmor. Lsts., Calcarenites, Calc. Ssts., Ctlc.-cemented Cgls. & Aggloms.	Lower-Midle Miocene
	Fuerteventura	1725	807	100	15	12	250	10	Lsts., Sandy Lsts., Calc. Ssts.	Plio-Quat.
				20	100 +	4	200	70	Calcirudites, Calcilutites, Lsts.	Palaeogene
				35	2200	5	265	90	Qtzites, Phtanites, Sh. Mars, Siltst, Sst, Lst, Calcarenites, Chalk, Chert, Qtz-Arenites, Dolomites.	Malm ( )-Cret.
	Gran Canaria	1532	1950	50	15 0	5	350	15	Pozzulanes, Ssts., Lsts., Silts, Sands, Psephites.	Miocene-Pliocene
	Tenerife	2058	3718	40	20	?	1100	6	Ssts., Sands, Pumice.	Neogene-Quaternary?
	Gomera	380	1482	5	'10s'	0.5	150	90	Fine-gr. detritals — silts, sands, siltstones, ssts. Many Qtz. & Qtzite grains.	MidleMiocene
	La Palma	730	2423	8	'100s'	13	950	Chaot. Torr. Struct.	Coarse Cgls.	Pre-Quaternary
CABO VERDE	Santo Antão	779	1979	.001	2	0.3	4	4	Calc. Ssts., Sandy Lsts., Shelly Cgls.	Neogene
	S. Vicente	227	774	4	100	4.5	140	5	Sandy, Crystall. & Ferrug Lsts., Vol.-Sandy, Calc.-cemented Cgls., Silic. & Calc. Sands.	Neogene
	Santa Luzia	35	395	1.3	1.5	1.75	200	15 Torr. Struct.	Sandy Lsts., Silic. K Calc. Sands.	Vindobonian
	Razo	7	164	.05	2	1	70	20 Slump. Beds	Sandy Lsts., Calcarenites.	Vindobonian
	S. Nicolau	343	1304	50	8	6	250	49	Marly, Marmor. Lsts., Sandy & Crystall. Lsts., Sandy Tuff. Lsts., Shelly Lsts., Cgls.	M.-U. Miocene
	Sal	216	406	32	10	4	70	3	Marmor. Lsts., Sandy Tuff. Lsts., Shelly Lsts, Cgls.	Vindobonian-Pliocene
	Boa Vista	620	390	25	7	12	80	3	Sandy-Silty Lsts., Marmor. Lsts.. Calc. Ssts. & Siltstones.	Neogene
	Fogo	496	2829	?	?	2.6	400	?	Micac. & Silic. Lsts, Crystall. Lsts.. Marmor. Lsts.	Vindobonian
	Brava	64	976	.05	3.5	1	350	25	Sandy & Silty Lsts., Calc. Tuffs, Vol.-Lst. Breccias.	Miocene or Pliocene
	Ilhéus Secos	3.5	96	.10	15	0.5	50	40	Pisol., Detrit., Corall., Tuff. Silic. & Ferrug. Lsts.	Miocene or Pliocene
	S. Tiago	991	1392	83	100 +	8.5	640	50	Cgls., Breccias, Lsts., Sands., Calcarenites, Clays. Shales, Marls, Lahars.	Pliocene(?) and Miocene
	Maio	269	436	50	175 +	6	80	36	Coarse Cgls., Cgl-Breccias, Sandy Lsts., Sands, Shales, Clays, Calcarenites.	Neogene
				100	1200 +	7	265	90	Calc., Silic., Mtrly & Silty Lsts., Flint Nodules. Shales, Vol.-Lst. calc.-cemented Cgls.	Malm (?) éocomian-Senonian (?)

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