SOME GEOMORPHIC ASPECTS OF THE AZORES ARCHIPELAGO

INTRODUCTION

The Azores archipelago lies between latitudes 37° and 40° N, longitudes 25° and 31° W, the nine chief islands totalling 2344 km^2, and reaching a maximum altitude of 2351 m.

All are of volcanic origin, but as distinct from other Macaronesian archipelagos, sedimentaries other than Quaternary have a very sparing development, outcropping over some 12 km ^{2} only in St.ª Maria. Average annual temperatures range between 14.3° C and 22.3 C, whilst average annual rainfall decreases from W to E, maximum monthly averages varying from 200 mm in Flores to 83 mm in St.ª Maria.

As with all these archipelagos, geological interest has always been directed to various facets of vulcanism, and literature devoted to other geological phenomena is pitifully few in number. In this context, only one geomorphological study is available, that of MOTTET (1972) treating of Terceira. With the aim of amplifying our general knowledge, some aspects of the geomorphology of the archipelago will be mentioned, and for further geological information reference can be made to the writer's work of 1976.

TOPOGRAPHY AND RELIEF

Notable mountain or hill ranges are the exception. S. Jorge, 55 km long and only 7 km broad at the most, is elongated parallel to a range which reaches 1053 m, whilst in St.ª Maria a topographic axis trends NNW-SSE across the eastern half of the island, rising to 587 m. Characteristic of the islands are one or several mountain masses, principal centres of eruptivity. Usually beginning with submarine lava emissions followed by subaerial outpourings and drenching by pyroclastic showers, created initial slopes in the islands. The building-up of eruptive centres in altitude increased the degrees of slope, and this, combined with positive vertical movements, most probably representing isostatic adjustments, resulted in all islands having very considerable slopes down to the coasts. Smooth, uninterrupted (except where coastal cliffs occur) slopes are well developed, e.g. the 30° S slope of Ponta do Pico, Pico, 35° slopes to the SW coast in S. Jorge, 25° slopes from the caldera rim to the cliff edge in eastern Corvo, 26° slopes to the cliff edge in NW Flores, etc. Agreed these are somewhate extreme values, but average slopes of 12°-17° from interior heights down to coasts or cliff edges are very common.

Lower, more level terrain is confined to western St.ª Maria, west centrl S. Miguel and parts of eastern Terceira, where tectonism has been largely responsible for such.

Relief is far less pronounced than in other Macaronesian archipelagos. Abrupt changes in altitude and hence strong relief occurs: (a) where caldera and crater rims drop down to interior floors, (b) throughout coastal sections where cliffs occur, some rising several hundred metres, (c) where streams have incised themselves deeply into the softer pyroclastics, creating narrow and deep (up to 150 m) valleys.

Views in the interior of the islands show (with the relief exceptions mentioned above) somewhat gentle, rolling topography, with an over-all slope towards the coasts. Viewed from offshore, the islands show pronounced cliffs separating interior tablelands with hill — and mountain-masses, from rocky shores.

CALDEIRAS

Volcanic landforms dominate the scene in all islands, a wide variety can be observed of diverse degree of perfection and stage of development. Here we shall mention only two forms, caldeiras and scoria cones, the former imposing by their size, frequency and intrinsic interest, the latter as forming unusual features.

The term «caldeira» is inappropriately used in the Spanish and Portuguese islands of Macaronesia, geologists of these and other nationalities confounding the use even more so. By caldeiras we

refer to large depressions of volcanic origin having usually circular, elliptical, or cirque-like forms, whose diameters — by common consent 1.6 km (one mile) at least — greatly exceed those of the included vent(s), the steepness of the inner walls and form of the floor being of minor importance. Size alone distinguishes caldeiras from craters, the latter being smaller. Every caldeira has been subjected to modelling by exogenic agencies to varying degrees, and indeed in some, such agencies appear to play a commanding role. No less has tectonism been operative in many, so that although initially such large depressions are of volcanic origin, exogenic and/or tectonic agencies have modified the original appearance, on occasion drastically.

Within the archipelago are 11 caldeiras, more than in any other in Macaronesia (MITCHELL-THOMÉ, 1980). Dimensions vary from 1.6 km to 7.5 km in diameter, caldeira perimeters range from 4 km to more than 22 km, heights from caldeira floor to bordering rims vary from 174 m to 860 m, with interior slopes ranging from 20° to 60°. The majority of the caldeiras are of Krakatoa type-great explosive eruptions of siliceous magmas in the form of showers and flows of pumice, with consequent collapse of the summit vent area. In Corvo subsidence took place during the later phases of shield growth (Galapagos type); the Agua de Pau caldeira in S. Miguel collapsed as a result of magma drainage through adjacent conduits away from the sub-caldeira magma chamber, (Katmai type), whilst Guilherme Moniz caldeira in Terceira shows somewhat linear type ring fractures with intermittent foundering over a long period, (Glen Goe type). (Terminology is that of WILLIAMS and MCBIRNEY, 1968).

Lakes are common within the caldeiras: two in Corvo, one in Faial, one in St.ª Barbara caldeira and two in Cinco Picos caldeira, Terceira. In S. Miguel, Sete Cidades caldeira has five lakes, including the enchanting lagoas Azul and Verde; there is still one in Água de Pau caldeira, and one in Furnas caldeira. Lakes vary greatly in size and permanence, those in Cinco Picos being really larger ponds wich often are dry in summer, whilst Lagoa Azul, largest of all, covers some 4 km², is at least 8 m deep, a permanent and most beautiful sight. Guilherme Moniz has a remarkably level floor, elevations varying not more than 4 m throughout an aera of some 4.5 km². In the many slight depressions, internal drainage creates ponds and marsh areas only during the wet season. This caldeira floor comprises highly vesicular basalt flows, at a distance appearing quite smooth but actually having extremely rough and irregular surfaces, unfavourable for any type of cultivation The Portuguese name «biscoutos» for such surfaces is indeed appropriate — irregular like cream-crackers. The four caldeiras in S. Miguel display the greatest attendant effects of vulcanism in the form of mineral springs, fumaroles, solfataras. At Furnas occur many mineral springs, hot and cold, alkaline, neutral and acidic, precipitation deposits of siliceous, ferruginous and sulphuric nature, such that here we have a spa for medical treatment. In St.ª Barbara caldeira, graben-type faulting between older and younger depressions has created a small stream, lake and marsh area, drainage having no outlet. The internal drainage of Povoação caldeira in S. Miguel is unique in showing a well developed dendritic pattern, the valleys being narrow, deep and choked with torrential conglomerate deposits. Here drainage is better established, vertical corrasion creating veritable canyons, 150 m broad and the same depth, coarse conglomerates filling the valleys up to elavations of 400 m, to the very foot of the steep interior walls. The firmer established drainage network here suggests this is an old caldeira, relatively quiescent for a longer period.

All caldeiras show to varying degrees of perfection radial drainage down exterior slopes, particularly well seen in Faial St.ª Barbara, Terceira, and Sete Cidades and Povoação caldeiras in S. Miguel. The extensive carpeting of pyroclastics, small areas of the islands, steep slopes, adequate rainfalls throughout the year are all conducive to active stream incision and adopting direct courses down to the sea.

Though the eleven internal caldeira depressions total only some 7 % of the archipelago area, they are such striking landforms, both externally, where their areal geomorphologic influence is much greater, and internally where enormous hollows have been scooped out of the earth, that their attraction to scientist and layman alike are such that as landforms their importance cannot be minimized.

CRATERED PENINSULAR AND INSULAR CONES

Scoria cones are liberally sprinkled throughout all islands, nearly all of which are cratered and form prominent hill masses. Here we shall only refer to two types of such cones. Gratered peninsular

cones are excellently displayed at Monte Brasil, Terceira, and Monte da Guia, Faial. The former, described in detail by AGOSTINHO (1950) and MOTTET (1972) occurs on the S coast on the outskirts of the capital, Angra do Heroismo. This peninsular cone has a diameter of 1.5 km, area of 1.5 km² rises to 205 m and is attached to the mainland by a 500 m long and broad isthmus reaching 25 m above sea level. The central crater is of Strombolian type, slopes formed by the piling up of showers of pyroclastics, with three interior emission centres, now forming level terrain, 90 m, 45 m and 34 m above the sea, crater walls rising to heights of approximately 200 m. The oldest eruption was submarine, the two succeeding subaerial outbursts following each other closely in time. A major fracture trends NW-SE through the structure. The entire edifice comprises tuff and lapilli layers which have undergone considerable pedogenesis. Blocks of basalt and ankaramite, torn loose from the substratum, are intermingled with the volcanics. Exterior slopes of the main crater average 30°, the coast being cliffed, especially on the W and S sides. The isthmus is not a tombolo formed of loose detritals but is an old lava flow lying beneath pyroclastics.

Agostinho remarked that nowhere else in the archipelago was there as large a tuffaceous structure as here.

Monte da Guia lies on the southern outskirts of the Faial capital, Horta. Another Strombolian cone, this one has a diameter of 1 km, with a land area of ca. 7 km², (though the area before foundering exceeded a square kilometre) and rises to 145 m. As distinct from Monte Brasil, this structure has been breached by the sea, semicircular walls opening to the S, and also here the attachment to the mainland is a true tombolo, of detritus rising 2-3 m above high tide. On the inner side a secondary cone joins the mainland. Two nested craters occur, covered by 6 m and 20 m of sea water rspectively. The cone is formed of indurated tuffs, those of the inner, older crater dipping to the NW, those of the outer, later one dipping to the S. Excellently preserved fossilized ripple marks, much dislocated by miniature faults, are notable features. Throughout three-quarters of the periphery of the structure there is strong cliffing, as high as 130 m on the SE side.

The above are the best examples of cratered peninsular cones, but less developed and/or preserved ones are as follows: at Capelinhos, Faial, where the 1957-58 eruptions took place forming an embryo island with a breached crater which, within a few months, united with the mainland; at Velas, S. Jorge are two cratered peninsular cones; at Morro da Vigia and at Ponta da Ferraria, S. Miguel; in SW Faial. Insular cratered Strombolian cones in various stages of growth and development occur. Ilheus das Cabras, 1.5 km off the S shore of Terceira, are the result of a single breached crater which was subsequently split into two islets along a NW-SE fracture. Ilheu de Baixo, 1 km off SE Graciosa, Ilheus de Madalena, 1 km off the NW. coast of Pico, Ilheu de Vila Franca, 0.5 km off the S. coast of S. Miguel are other examples. Imminent, in geological time, are several other instances, e.g. NW Graciosa.

MARINE ABRASION PLATFORMS AND TERRACES

There is vagueness and considerable confusion regarding these features in the Azores. MORELET (1860) was the first to mention the former, believing such to occur between altitudes of 120-130 m in St.ª Maria. FRIEDLÄNDER (1929) first reported several platforms in the various islands: at 100 m in St.ª Maria and in Graciosa, in the islet of Monchique off the W coast of Flores, in the islets of Praia and Baixo off the E-SE coasts of Graciosa and in the Madalena islets off the NW coast of Pico. BERTHOIS (1953a) referred to a platform in St.ª Maria between 90-100 m, and possibly another between 100-110 m. ZBYSZEWSYK (1961) reported three platforms in S. Miguel at altitudes of 15-30 m; 50-75 m and 80-120 m. BERTHOIS (op. cit.) amended some of these statements, e.g. in Graciosa there was an error in altitude — should be 60 m and not 100 m — and further the surface was of continental, not marine origin, whilst the surfaces seen in Praia and Baixo were of structural, not marine origin; and the same probably applied to the Madalena islets. FRIEDLÄNDER (op. cit.) thought that most of the western half of St.ª Maria, average elevation 150 m and sloping westwards, was a 'platform emergent in relatively recent times, but BERTHOIS reduced the elevation to ca. 90-110 m. The writer would append the following remarks. The western coast of Terceira is bordered by cliffs rising as high as 150 m, leaving a narrow strand usually not broader than 50 m. In places, e.g. between Pontas Rubras and Queimado, a stepped arrangement occurs, sections up to 10 m wide (three have been noted), the upper two of which have all the appearance of having been wave-cut and polished. Their elevations above present high tide are 4-4.5 m and

6-7, with a very slight inclination seaward. FRIEDLÄNDER referred to «Strandterrassen in einer Höhe von etwa 100 m» in eastern Terceira, which BERTHOIS incorrectly interpreted to mean marine abrasion platform — Abtragungsfläche or Abtragungsebene. The writer has seen no evidence of platforms here, though most likely a marine terrace occurs at 7-9 m and certainly at 15-20 m. In St.ª Maria, W and NW of S. Pedro are intermittent vestiges of a platform with polished pebbles and shell débris, and a few metres eastward rises a cliff some 5 m high with wave-cut notches at the base. These vestiges lie between 195 m and 202 m, being the most easterly seen in the island. Here then in St.ª Maria marine abrasion platforms occur at elevations of some 90 m to 200 m, and the contention of BERTHOIS and ZBYSZEWSKY et al (1961) that more than one platform occurs seems correct, three at least.

The southern extremity of Corvo, beginning at 150 m, shows gentle slopes southward. Relatively recent lava flows emanating from centres nearby of 500 m and 375 m and flowing southward, here display lobate forms, at the coast forming concentric islets and stacks, inland forming ridges, all convex to the S and excellently seen in arial photographs. FRIEDLÄNDER (op cit.) claimed there was a 30 m high marine terrace here and both MEDEIROS (1967) and ZBYSZEWSKY *et al* (1967)) speak of a 'platforma' here. The writer believes neither are present, the relatively sudden decrease in slope of the basement over which the lavas poured, had a braking action on the latter and allowed flows to pile-up and thus increase in thickness so as to form a gentle, relatively smooth surface, for traces of either marine deposition or erosive action are lacking.

In the Azores then, as per present knowledge, marine abrasion platforms occur at elevations from 4 m to 200 m above present sea level.

Marine terraces can be identified in all islands, but individual numbers, clarity and extents vary. (Table I) They are best observed in St.ª Maria where six levels can be recognized, believed to date from Calabrian to Flandrian times. These terraces usually show alternations of marine gravels and sands, some of the former being well cemented, clayey sands, coarser gravels and pebbles, marine conglomerates, shelly sands, and limestone pebbles of Miocene age which have been weathered from outcrops and occur as scree deposits within sequences.

TABLE I

Marine Terrace (12-20) and Marine Abrasiou Platforms (15-30§) in the Azores Archipelago Elevations in m

Age	Islands W								E
	Flores	Corvo	Faial	Pico	S. Jorge	Graciosa	Terceira	S. Miguel	Sta. Maria
Flandrian		1-1.5 ?	0.5-2	3-5			4-4.5§	4	1-1.5 3-4.5
Neo-Tyrrhenian (Tyrrhenian III)	8-15			5-6	8-9	6-9	6-7§ 7-10		6-12
Eu-Tyrrhenian (Tyrrhenian II)	12-20		15-17				15-20	15-30§	12-15
Paleo-Tyrrhenian (Tyrrhenian I)									
Milazzian (Neo-Sicilian II)								50-75§	50-60
Paleo-Sicilian I								80-120§ 80-90	90-100§ 100-110§ 80-100
Calabrian									195-202§

ZBYSZEWSKY *et al* (1968) mentioned old beaches in the extreme N of Flores, varying in altitude between 30-150 m, and newer, lower, ones at 8-15 m and 12-20 m. The extreme mixing of sands, gravels, pebbles along with pyroclastic material and torrential deposits, makes distinction difficult, but such granulometric studies as have been made show no indications of marine origin of such deposits at higher elevations on the gently sloping land along the N coast, fronted by cliffs up to 80 m high. On the other hand, terraces up to elevations of some 20 m certainly can be observed along both the W and E coasts.

The 7-10 m marine terrace noted by BERTHOIS (1953a) in Terceira is well expressed at Praia de Vitoria, and 3 km SW of here and inland from Cabo da Praia, terraces occur at 7-9 m and 15-20 m. The 'Ebene' at 60 m in Terceira, 'zwischen Praia de Vitoria und Lagens' (as also at 45 m in Graciosa 'zwischen Guadalupe und Victoria')) mentioned by KREGCI-GRAF (1961) are structural features and not of marine origin. MOTTET (1972) makes no mention of marine terraces in Terceira, and ZBYSZEWSKY *et al* (1971) merely quote BERTHOIS.

BERTHOIS (1953b) commented upon the frequency of marine terraces at elevations between 5 m and 8 m within the Azores, e. g. low terraces have maximum altitudes of 4.5 m in St.ª Maria, 6.4 m in S. Miguel, 7 m in Terceira, 8 m in Graciosa and exceptionally, 9 m, 5 m in Pico, 2 m in Faial. He drew analogies to the prevalence of terraces at such altitudes in Portugal — and, we would add, in Mauritania, Morocco and Gibralter — but realized that such correlations were more apparant than real. The Azores, being relatively highly unstable areas, any correlations of terraces can only be made within restricted time limits, though those of St.ª Maria and Faial may suggest greater stability of the Azorean socle since Grimaldian times.

What does become apparent from an investigation into marine abrasion platforms, terraces and occurrences of Tertiary sediments in the archipelago — the last-mentioned attaining altitudes of 400 m in St.ª Maria — is that degree of uplift has increased from W to E. In St.ª Maria, easternmost island, platforms, terraces and Tertiary strata occur higher than in the rest of the archipelago. AGOSTINHO (1937) took St.ª Maria to be a special island, the Miocene sediments which outcrop here, occurring at depth westward in the rest of the archipelago, but greater uplift in the E caused them to be exposed only in St.ª Maria. Marine abrasion platforms and terraces all appear to be of Quaternary age, and presumably it was then that greater uplift occurred in the E. HARTUNG (1860) and AGOSTINHO (op. cit.) both attributed such greater uplift in the E to closer proximity to Miocene diastrophism in Europe, associated with Alpine orogeny, but this is questionable. The eastern Azores lie some 1500 km from the nearest European mainland, not close to a mainland (Africa), like the Canary Islands where possible orogenic linkage with Alpinism can be suggested.

COASTS OF THE ARCHIPELAGO

Seldom do the islands rise gently above the sea, and typical of all islands and throughout much of each island are cliffs and precipitous walls fronting the ocean. (Table II) Bold, rocky cliff scenery is characteristic, the foreshores being formed of a chaotic mass of fallen rock débris incessantly pounded by the seas. In Flores, cliffs more than 50 m in height occur throughout 40 % of the coastal

TABLE II

Coastal Topography

Island	Area km²	Max. Alt. m	% of Total Coastal Periphery			
			With Cliffs		Steep rises from coasts (20º & ≥)	Sand, Gravel, Pebble, Cobble Beaches
			< 50 m	> 50 m		
Flores	143	914	12	40	8	7
Corvo	17	718	16	26	56	< 1
Faial	173	1043	28	31	18	8
Pico	446	2351	16	6	14	< 1
S. Jorge	246	1053	10	26	10	7
Graciosa	61	402	33	16	6	3
Terceira	401	1021	82	10	—	4
S. Miguel	757	1103	15	11	12	5
St.ª Maria	97	587	10	15	35	4

periphery, being reduced to 6 % in Pico. No less than 92 % of the coasts of Terceira are cliffed, 10 m and higher. Steep rises from coasts, either as pronounced scarps or then more gentle but longer slopes — as in Pico — are absent in Terceira but constitute some 56 % of the coastal periphery of Corvo.

Some coastal regions are indeed most imposing, e.g. for some 20 m along the western coast of Terceira a continuous cliff section more than 100 m in height, completely isolates the shoreline from the upland interior. On the NW coast of Corvo, abrupt declivities up to 60° link the caldeira rim with the sea below, and except in the extreme S, everywhere the cliffs present unscalable walls — by ordinary means at least. Extremely precipitous slopes rise up to 700 m here.

Two excelent examples of areal growth of volcanic islands can be seen in Flores and Faial. In the Fajãzinha-Fajã Grande area of western Flores, older andesitic flows formely fronted the sea, forming cliffs up to 500 m high, in semi-circular fashion enclosing a marine embayment. Thereafter from three submarine centres, olivine basalts were emitted, flowing outwards towards the NW, W and S. These basaltic flows as well as older pyroclastics and a large quantity of coarse scree deposits and rockfall material built out the land at the expense of the sea. The result is that some 6 km² of land has been added to the island, said land rising to 285 m in one of the scoria cones, and extending outwards from the old andesitic cliffs for some 2 km. The basaltic episode here represents the youngest manifestation of vulcanicity in the island, certainly Quaternary, and because of the relative freshness of the lavas, probably dates from Holocene. Recent vulcanism has 'straightened out' the coast here, a former deep embayment being changed into low land with a smooth, slightly curved shoreline.

A very recent event, only twenty years ago, likewise changed the coastal appearance of western Faial. Between September, 1957 and October, 1958 violent vulcanism and powerful seismism began by forming an islet 1 km from the extreme western end, at Capelhinos, from a depth of 90 m, within 48 hours building up a scoria cone 80 m above sea level. During the three pseudovulcanian and vesuvian or plinian phases, fissural eruptions and explosive activity continued to form land, varying in elevation from 15 m to 160 m, spreading activity uniting the initial islet with the mainland. As a result, instead of a prominent N-S extent of cliffs up to 170 m high forming the extreme western tip of the island, a bulbous-shaped addition of land was added, 1.75 km^2 in area, formed of basalts, scoria of various dimensions, with smooth, dark-coloured sands along the shores fringing the scoria. Where once high cliffs fronted the ocean, with many offshore stacks and skerries rising from depths of up to 90 m; we now have land rising gently from 15 m to 160 m, uniting the original centre of vulcanicity with the mainland, lower intervening land having relatively straight brownish beaches. The added area of less than 2 km^2 might seem little indeed, except that we should note that this construction was accomplished in thirteen months!

The prevalence of so much cliffing and extremely steep descents down to coasts in the Azorean islands frequently results in streams losing their channel identities after having plunged over the edge. In NW Faial where the distance between scarp base and high tide mark is as much as 500 m, scarps rising to over 300 m, a dozen or so streams negotiate this distance in a maze of indefinite runnels threading their way through coarse scree and detached andesitic blocks becoming much reduced in size as the sea is approached, where powerful marine erosion pulverizes this material to smaller size, allowing of greater infiltration of these fresh waters, so that all traces of the upper streams have become lost down below.

In NW Corvo especially but also in NW Flores, experiencing orographic rains coming from the NW and amounting to as much as 1400 mm annually, the windward slopes are so precipitous that rains have no opportunity to collect themselves into channels, and for several kilometres said slopes show waters tumbling down in the form of sheet flows, seeking the direct and quickest route to the sea. Loose débris at the base are so choked with water that one sinks up to the knees in attenpting to traverse the region, which obviously is devoid of all habitation, vegetation no less.

Sand beaches are rare, the sporadic beaches being of gravel, pebble and cobble size. This fact becomes obvious in reading travel brochures, which instead advertise «rugged, rock-bound coasts». Lack of outcropping sediments, other than in St.ª Maria, and the predominance of andesitic and basaltic volcanics and pyroclastics with melanocratic minerals, means that beach material has darker hues Seldom are sands 'golden' or are gravels, etc. lighter coloured, and indeed brownish and blackish beaches are quite common.

The degree of indentation of the coasts varies greatly, Corvo, Pico, S. Jorge and Faial having smoother coastal outlines; Graciosa, S. Miguel and Terceira more irregular, whilst Flores and eastern St.ª Maria are highly indented. The reasons for such variations are not readily apparent. Offshore submarine slopes are ca. 11° down to the 20 m isobath, 2° from −20 m to −100 m. Offshore to ca. 1 km from the coasts, waters do not exceed 20 m in depth, but the long fetch of waves coming chiefly from the W, NW, creates considerable swells, seas become more aggitated in-shore, so that within this 20 m depth waves have abundant energy to erode drastically.

There is of course the fundamental distinction between consolidated volcanics and less coherent pyroclastics, but otherwise distinctions within these groups, as regards resistance to erosion is negligible. A high proportion of the cliffed and scarped coasts of the islands are formed of lava flows, and occasions where pyroclastics have been cliffed, admittedly forming bays, it is older ejectamenta of the earliest eruptivity that have been embayed, not the younger.

Flows and pyroclastics show seaward dips, on occasion up to 55°, decreasing in degree the further removed from eruptive centres, and in coastal sections, dips seldom exceed 10°. Unified slabs of rock dipping gently into the sea do not lend themselves to marked indentition, and yet similar volcanics with roughly similar dips at the sea edge can show wide variations in degree of indentation.

Fracturing and dyke formation, other than in Corvo and Flores, are not more prevalent in coastal areas then elsewhere, and in the case of the highly indented Flores coasts, dyke occurrences at high angles to the coast are just as likely to be embayments as headlands. (But see eastern Faial under 'Structure' below.)

For Terceira, MOTTET (1972) claimed that trachytic flows were thicker and more resistant to erosion than thinner basaltic flows, the former forming prominent headlands, yet here there are several smaller but just as prominent andestic and basaltic headlands. Certainly for the archipelago as a whole, we cannot subscribe to the view of MOTTET.

Less prominent coastal irregularities are formed of somewhat ogival shapes of loose Quaternary detritals, well seen in S. Jorge and S. Miguel, which actually are headland beaches formed by longshore currents.

To account for variations in degree of indentation of the coasts, the writer is inclined to develope the idea that lava eruptions from higher central areas did not always flow downwards as more unified fronts but rather in marked lobate fashion, governed by the topography of the surface over which they flowed and the physicochemical characteristics of the lavas in question, so that some lobes extended further than others. Those lobes extending further seaward formed headlands, those less extended took on the features of embayments. Pyroclastics are usually intercalated with flows which, in both headlands and embayments were more readily attacked by the waves, flows were undermined, lost stability, formed rockfalls, but in the embayments where erosive action was less, there is a greater development of loose detritus, so that essentially, headlands are retreating, embayments extending seaward. But as so much of the vulcanicity is later Neogene and younger, erosion-deposition has had little time to smooth-out coatal irregularities.

The wide development of cliffing in these islands and the heights of such on occasion, cannot be due solely to littoral erosion. From several sources we have evidences of uplift of the islands, isostatic responses attempting to restore equilibrium, and such uplifts are the major and initial cause of cliff development, the many, thick sequences of floks presenting abrupt seaward extremities, gravitational mass movements and marine erosion modifying these cliffs as also the steep scarps.

The Flandrian rise in sea level during the past 20-25,000 years has made the Azorean coasts ones of submergence. As *Holmes* (1965) has pertinently remarked: «The occurrence of 'raised beaches' looks like a contradiction (where Flandrian transgressions have taken place). But it only means that what we now see is the algebraic sum of a long history of ups and downs. The last major eustatic rise of sea-level has ensured that a majority of shore-lines still retain the characteristics of submergence».

STRUCTURAL CONTROL

Fissural eruptions, especially scoria cones, most of which are cratered, are well seen in some islands. In S. Jorge, e.g. the alignment of such along linear NW-SE trends can be traced for distances up to 20 km, with some 50 individual and coalesced cratered cones.

Fissural trends usually parallel one another, but high-angle intersections, again marked by scoria cones, occur in S. Jorge, and radical trends about major eruptive centres are well exemplified around St.ª Barbara caldeira in Terceira. Noticeable is the fact that whilst the majority of fissures trend NW-SE, dykes more generally strike at right angles to this, the latter particularly evident towards coastal areas where prominent dykes cause walls trending inland in a NE-SW direction, intervening areas being deeply gullied.

Only in NE Terceira and eastern Faial is there manifest faulting control of the landscape where landforms owe more to tectonism than vulcanism. In this part of Terceira, NW-SE trending faults outline a graben, sloping to 20m high cliffs at the NW end, a somewhat steeper inclination to the SE where sandy beaches and marsh areas occur at Praia de Vitoria. This graben, 8 km long and 3.5 km broad, is bounded by a fault scarp on the NE (above which rises the Serra de Santiago to height of 124 m) and to the SW by a probable faultline scap. Within this graben has been constructed the largest and international airport of the archipelago, that of Lajes (=Lagens). The prominent fault scarp to the NE separates the Serra de Santiago region of andesitic flows from alluvial and pyroclastic material forming the graben floor.

In eastern Faial, NW-SE aligned fractures, extending from the high central caldeira area to the E coast, have created a series of horsts and graben, subsidence being more dominant than uplift. The network of andesitic flows here resembles a drainage network, the former coalescing towards the coasts to form prominent hill masses.

The recency of vulcanism here is testified by the fact that andesitic and pyroclastic of more compact type material is free of dissection by lateral streams, and instead interfluvial areas present smooth slopes to the N and S. *Berthois* (1953a) claimed that fault throws of up to 130 m could be observed in coastal sections here. Bathymetric contours in the channel to the E between Faial and Pico suggest that several of these faults continue eastwards towards Pico, and in the latter island, similar orientated fissures outlined by scoria cones in the western part thereof could be further extentions of such fractures. Here in eastern Faial, graben are represented at the coast by embayments, horsts by promontories.

Certain more rectilinear coastal trends elsewhere are suggestive of fault control, e.g. the N coast of Flores, the coasts of western

S. Miguel, N coast of S. Jorge, etc. but at this stage of our knowledge these are only suggestive, not proven.

MACHADO *et al* (1972) postulated several 'rifts' or graben crossing islands, e.g. in S. Miguel, Faial, Graciosa, Pico, Terceira, S. Jorge, which they took to be off-set parts of the Mid-Atlantic Ridge, moved laterally by transform faulting. The largest (in breadth) of such 'rifts' crosses West-Central S. Miguel, where lower, more gentle undulating landscape extends from the N to the S coast. Within this 100 km² area, surface streams are entirely lacking, though plentiful E and W thereof, there is no pronounced rain barrier here, the area in question receiving 1100 mm average annual rainfall, nor do the rocks here — mostly basalts, with minor andesitic flows and some pyroclastics — show any unusual porous and/or permeable qualities. It could be that boundary faults so lowered the intervening area (maximum elevations of some 350 m at the peripheries but average elevation ca. 150 m) that there was a lack of adequate slop for young, post-ruptive streams to carve out definite channels over the lava fields, whose fresh state indicates a relatively recent age of eruptivity here.

Seldom in any area is the topographic reflection of faulting conclusive in proving faulting. Fault scarps are relatively rare features, and though fault-line scarps seen to be commoner they are not necessarily easier to recognize. Though the islands have undergone considerable fracturing, with greater seismism than in other Macaronesian archipelagoes — certainly within historical times it appears in general that faulting has exercised little control in landscape development within the Azores. On the other hand, tectonism in the form of isostatic uplifts, has had a profound say in coastal aspects and rejuvenation of streams.

CONCLUSION

Landscapes over the world, as we see and study them today, are products of very recent geological times, not older usually than Neogene.

Vindobonian sediments outcropping in St.ª Maria are sandwiched between basalts below and above, the earlier partially submarine volcanic phase likely dating from not older than Early Miocene or Upper Oligocene. Whether or not vulcanism in other Azorean isl-

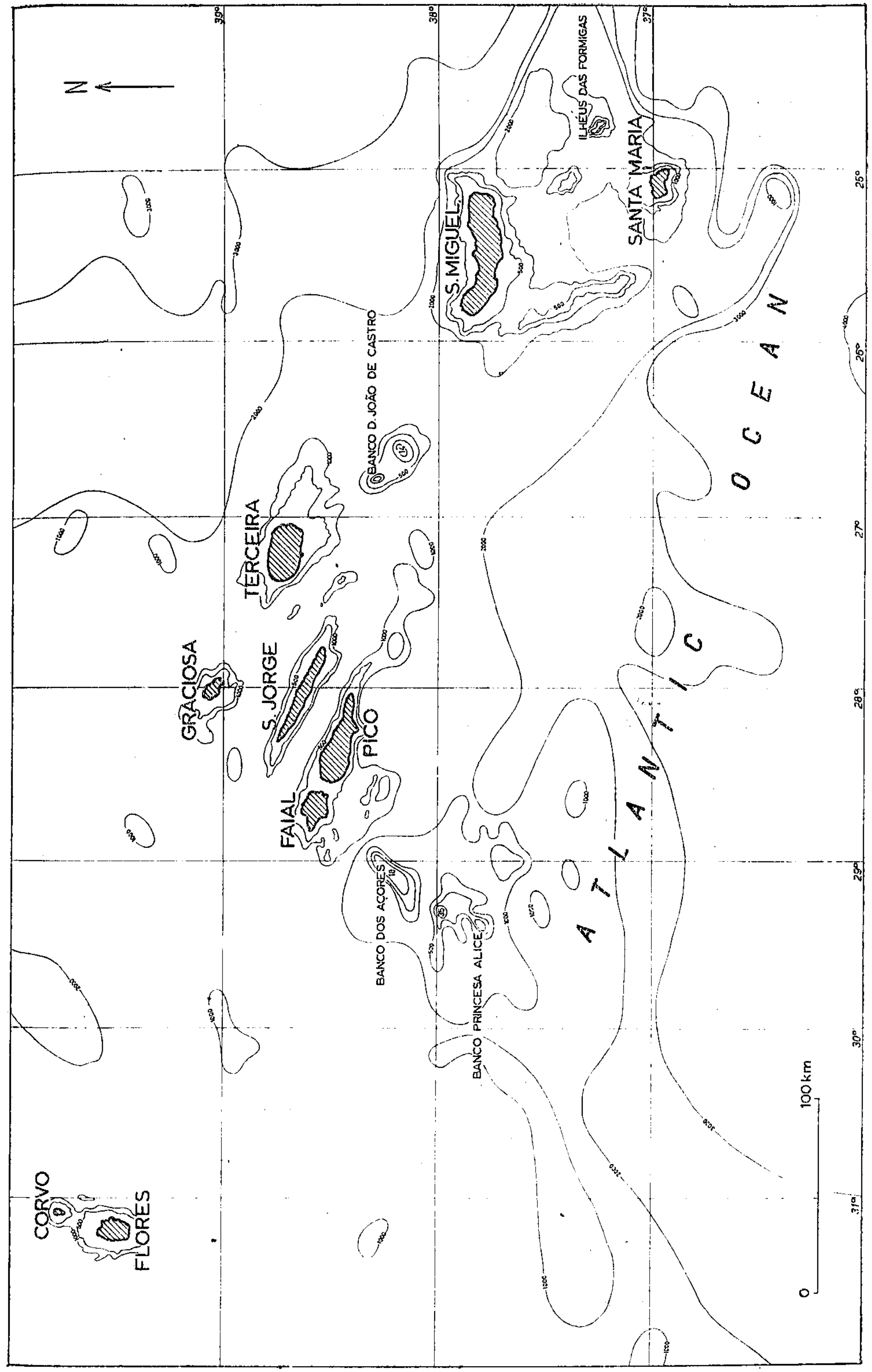

Fig. 1 — Azores archipelago

ands dates only from post-Vindobonian times, as AGOSTINHO (1937) thought, cannot satisfactorily be answered at this time, but it can be taken that the archipelago is not older than Neogene.

At the site of the archipelago we can assume therefore that vulcanism began some 20-22 million years ago, but it was in the Late Neogene-Quaternary, comprising some 7 to 8 million years, that vulcanism was most rampant.

The Azores, as we have already mentioned, are highly seismic, further instability was brought about by positive and negative vertical movements of the islands, eustatism has affected the archipelago, fracturing, jointing, dyke formation bear witness to stress conditions. It becomes obvious then that within the relatively short time available, nowhere has the geomorphological cycle had time to pursue its uninterrupted course for any considerable geological time. Dominating the scene everywhere are landforms of volcanic origin, but for the above reasons, no profound modelling of such has taken place. Stratigraphically, volcanically, tectonically and geomorphological the archipelago indicates relative youth, with new vulcanism repeatedly presenting new forms for sculpturing.

Ideal climatic conditions, initial nutritive soils which have been carefully tended for some 500 years, the industrious, conservative attitude of the islanders, the prevalence almost everywhere of vegetation, crop and grazing lands lending verdant, rich aspects to the landscape, thus present islands of infinite attraction to tourist and scientist alike.

R. C. MITCHELL — THOMÉ

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RÉSUMÉ

Quelques aspects géomorphologiques de l'archipel des Açores. Présentation des formes les plus typiques du relief des différents îles: les onze caldeiras, les cônes à cratères stromboliens qui forment des péninsules ou des ilôts, les plate-formes d'abrasion et autres terrasses marines, les falaises qui constituent l'essentiel des littoraux et les formes dépendant directement de (fractures). L'intérêt et la richesse de ces formes font regretter que davantage d'études géomorphologiques ne leur soient pas consacrées.

† Bol. Mus. Mun. do Funchal, 33, 141, 5-46, Funchal.