ON SOME UNUSUAL VALLEYS IN MACARONESIA

by
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INTRODUCTION

A valley can be defined as: «Any hollow or low-lying land bounded by hill or mountation ranges, and usually traversed by a stream or river which receives the drainage of the surrounding heights». It is commonly a linear depression, the result usually of fluvial erosion.

Valleys of smaller volcanic islands (Tenerife, 2058 km^2 is the largest of these Atlantic islands) in general have rather simple drainage networks, the streams — which by custom are considered smaller than rivers in all dimensions — flowing radially outward from higher island areas to the peripheries. Some height or heights dominate the scene, and gravitational laws control the terrestrial hydrography so that the flowing waters take the shortest routes to the coasts. Hence drainage networks tend to display relatively straight courses of radially-directed streams, well entrenched in the higher reaches. Such streams, due to relative shortness of length combined with relatively steep slopes (initially at least) are destined to hurry on downwards, significant meanderings are not conspicuous, extensive anastomosing is lacking, the pattern shows the domi-

nance of the main channel, tributaries being distinctly minor, and thus individual stream groups show dendritic patterns. For obvious reasons, streams cannot be long, broad or deep, and though during pluvial periods they may carry heavy loads, deposition along the courses are few except where reduced gradients nearer the coasts occur. Thalwegs tend to be steep, transverse sections likewise show steep valley sides, the role of vertical corrasion is dominant, longitudinal profiles are highly irregular, often even into a stage of relative maturity where the stream continues to erode through rocks of varying resistance, e. g. lava flows and pyroclastics.

In all such features, valleys of volcanic islands are akin to those in headwaters areas of continental valleys, and in general it may be said that such island valleys are more 'simple', more 'straightforward' in characteristics and patterns. Thus when we find valleys in these islands which depart from the usual traits, this must arouse our interest, for certain factors have interfered with the more 'normal' evolution.

Never can one ignore the climatic regime pertaining to a region. Macaronesia extends from latitudes 40°-15° N, from longitudes 31°-13° W. Our definition states that «usually» a stream traverses a valley, but this does not hold for most of these Atlantic islands, yet in dry and wet seasons, the valley is always there. Average annual rainfalls vary from 950 mm in the Azores to 260 mm in Cape Verde; average annual temperatures from 17.7° C in the Azores to 24.5° C in Cape Verde.

The skies of the Azores are seldom cloudless, whilst the converse holds in Cape Verde, hence evapotranspiration varies annually from negligible quantities in the former archipelago to as much as 500-2180 mm (depending on which island) in Cape Verde. Rainfall is adequat throughout the year in the Azores, but Cape Verde suffers from serious deficiencies, such that most valleys in the former

have streams flowing much of the year, they are intermittent, whereas in the latter, only two very small streams in NE Santo Antão are permanent, the rest are all ephemeral. It follows then that fluvial erosion is a much more potent and constant phenomenon in the Azores, a highly sporadic, erratic feature in Cape Verde.

In Macaronesia, there are several valleys of particular note in forming features less common in volcanic islands, and these will be commented upon below.

AZORES ARCHIPELAGO

In NW Santa Maria the Rib. Lemos flows for some 4.5 km NW to the coast, with land rising to 190 m between it and the N coast. In the vicinity of Faneca, the stream is heading towards the N coast, and here, where a saddle occurs betwen higher terrain in the N coastal heights, at an elevation of ca. 120 m and only some 500 m from the coast, a small tributary enters from the S. But the Lemos does not take advantage of this gateway to the N coast and instead continues to flow westward to the sea near Anjos, ca. 1.9 km distant. In the saddle area occur friable sands, sandy limestones and conglomerates, and a gully drops down to the N coast, occupied by a tiny torrent in times of rain. Stream divergence has taken place at the saddle area, the upper Lemos and the S-bank tributary exiting northwards to the sea at this locality. Now however, the lower Lemos has effected a capture, and diverted these two other streams westward. The upper reaches of the Lemos down to the saddle have an average gradient of 1 in 10, and from here to the mouth near Anjos, 1 in 14. Thus, as regards erosive ability, the upper stretch is more favoured. However, the lower Lemos, in working headwards, encountered softer, less resistant rock material at the saddle area, hence eroded faster than over the volcanics

and coarse breccias in the lower course. It was thus able to extend its headwaters and tap the upper course and so cause the diversion. The route N from the saddle down to the coast is thus a wind gap, though in times of rain, a small torrent rushes down the gully to the sea.

In western Terceira, NW and SW Faial and western Flores there are valleys which, in the wet season, display streams plunging over the brinks of cliffs and spewed forth as indiscriminate sheets of water to the strand below.

In this part of Terceira, cliffs attain elevations of 170-200 m, with brinks as close as 100 m from the sea. Down the slopes of the Serra de Santa Bárbara caldera, valleys radiate to the NW, W, SW and S showing this feature. Down the cliff face and across the strand below to the sea there are no identifiable channels of water, the waters tumbling down as dispersed sheets, forming a soggy terrain below, most chaotic in appearance, a rubbly, oozing mass of wet rock débris.

In Faial similar conditions are met with, in the NW part cliffs rising to 325 m in places, the edges up to 500 m from the water's margin, whereas in the SW, cliffs rise up to 260 m, the brinks up to 250 m from the ocean. It is noteworthy that along the NW coast, the Rib. Funda, and lesser so, the Rib. das Cabras, show deep indentations into the cliffs (at the former extending for ca. a kilometre inland, with valley walls as high as 310 m above the valley mouth) and that the streams between the Cabras and Funda and to the N of the latter flow over andestic flows principally, whereas at the indentations, softer pyroclastics are prevalent. On the other hand, in the SW area, not a single stream maintains its identity over the cliff face to the shore (cliffs as high as 260 m), and further, this shoreline at the sea edge comprises rubble of the coarsest size, whereas in the NW, the shores are sandy. In both instances, streams are flowing down the slopes of the central caldera, whose rims reach an elevation of 1043 m.

In the Fajã Grande-Fajazinha region of western Flores, where Quaternary vulcanism has extended the land up to 2 km out from the older andesitic cliffs (Mitchell-Thomé, 1980), only one stream, the Rib. Grande manages at most times to maintain its identity right to the sea edge. But N of this area, all streams manage to do this, plunging over cliffs as high as 550 m and up to 1.1 km from the edge of the ocean. These more northerly streams flow over terrain where basaltic and andesitic lavas are more prominent than pyroclastics, in wet periods these are full, powerful small streams, their energy being strong enough to maintain a continuous channel down these very steep slopes. (It should be noticed in passing that Flores has the most highly indented coasts of any Macaronesian island).

In the respective areas of these three islands, slopes down which the streams flow to the brinks of the cliffs are almost the same — ca. 1 in 4.7, the terrain being overwhelmingly formed of pyroclastics in Faial, ca. 50-50 pyroclastics-lavas in Terceira, about 30-70 pyroclastics-lavas in Flores. As regards rainfall, there is little difference between the western exposures of these three islands, with a decrease in average annual rainfall from 1430 mm in Flores (at Santa Cruz das Flores on the E coast) to 1130 mm at Terceira for the island in general. Rainfall is such in these parts of these islands that streams usually have adequate flows in channels throughout the year. Today, the Azores is the most unstable seismologically of all these archipelagos, Terceira and Faial have shown vulcanicity in historic times (Mitchell-Thomé, 1981), Flores in the late Holocene. In these three islands, marine abrasion platforms and/or marine terraces are found, in Terceira, platforms to 7 m above SL, terraces to 20 m; in Faial, terraces to 17 m; in Flores, terraces to 150 m; one or the other are found in all the other Azores islands and in Santa Maria we have marine limestones outcropping 400 m

above present SL (Mitchell-Thomé, 1976). All such phenomena testify to vertical movements (at least partially) of these islands. One might wish to invoke rises of the near-shore sea bed as causes of strands below the cliffs, prior streams meeting the sea at cliff edges, but the relatively great height of these cliffs plus the purely local nature where such streams suddenly plunge over cliff edges, taxes one's credulity in assuming very localized tectonism or rises of the level of the ocean. We are thus led to conclude that there are no clearly apparent reasons why in W. Terceira, NW and SW Faial streams loose their identities from cliff edges to the seashore, yet do maintain such in the major part of W. Flores.

In São Miguel, between the N and S coasts in the narrowest part of the island (757 km²), is a region with scarce a valley throughout a zone measuring ca. 12 km E-W and 8 km N-S. This «Région des Pics» of Zbyszewski (1961) has, scattered here and there, dejection cones rising to 486 m in Serra Gorda on the western edge, and heights of up to 386 m on the divide between the N and S coasts. In this area there are two distinct geological zones, one where pyroclastics dominate, the other where basaltic-andesitic lavas are more extensive, some of which date from historic times. It is noteworthy that to E and W of this «Pics» area, where pyroclastics occur almost exclusively as outcrops, there do occur distinct valleys, and indeed the only significant stream in the region reaches the S coast at Lagoa, for half of its length coinciding closely with the lavas-pyroclastics boundary, and all its tributaries rise in the ejectamenta region.

In an island otherwise well supplied with streams, this inter-coastal area of gently rolling landscapes dotted by prominent scoria cones, Machado *et al.* (1972) have postulated a possible rift striking NNE-SSW across the island which coincides well with the lava outpourings. It is in this inter-coastal part where Faye anomalies attain

their lowest values in the island (150 mgls) and Bouguer anomalies reach 150 mgls compared to 140 mgls in the extreme W of São Miguel and 180 mgls in the extreme SE (Coelho, 1968), and here also the normal Brunhes magnetic polarity zone occurs (Machado *et al.*, 1972). Both the above gravity anomalies are intimately related to elevation, so that there is a broad correlation with the topography and relief. It does seem therefore that tectonically this is a critical zone, and here also recent vulcanism has poured forth its lavas. It could be that faulting associated with rifting has lowered this intervening zone of billowing landscape with its scoria hills, that tectonism and vulcanism being so relatively recent in geologic terms has meant that streams have scarce had time to carve out valleys in the more resistant, relatively fresh basaltic-andesitic lavas, thus creating the significant lack of valleys and streams. The absence of, valleys in a terrain is just as necessary of explanation as any other characteristics of the terrestrial hydrography.

In the Povoação caldera of eastern São Miguel occurs a perfect dendritic pattern of the drainage network. The circular walls of the caldera reach heights of 960 m, the caldera floor at lowest altitude, ca. 100 m, with a wall periphery of at least 17 km in length (Mitchell-Thomé, 1980). From high, very precipitous upper slopes all around the peripheries, tributaries descend and converge towards the exit at Povoação on the S coast. At greater heights, deeply-incised valleys show basaltic and trachytic lavas outcropping as well as much pumice, but torrential, chaotic conglomeratic-brecciatic deposits are the most striking constituents, mantling interior slopes and valley bottoms. As per Zbyszewski (1961), the caldera is of explosive-collapse origin, hence of Krakatoa type. At either side of the main valley at Povoação, and rising to 100-200 m almost prevent the stream from gaining an exit (the southern rim

of the caldera reaches a height of 435 m ca. 1 km due E of Povoação village) the interior drainage area seeking an exit barely 300 m wide between 50 m elevations on eitherside.

MADEIRA ARCHIPELAGO

In Madeira, the Janela is the longest stream in the island, some 22 km in length, and in places the valley is 5 m broad! (Mitchell-Thomé, 1979). From its source at 1580 m, it has three distinct gradients: 1 in 21 across the initial uplands of Paul da Serra; 1 in 5 in a gorge-like middle section; 1 in 17 from thereon to the sea. The stream traverses the Serra Post-Vindobonian Complex, where ejectamenta predominate in the upper part, the Vindobonian Complex where effusives are dominant in the middle reaches, the Basal Complex in the lower section where again ejectamenta are typical (Zbyszewski, 1971). It is further to be noted that in cross-sections, steeper, narrower inner valley slopes coincide with outcropping Basal Complex, gentler, higher slopes with the Vindobonian Complex. For such a relatively short stream to have valley breadths almost one-quarter of the total lenght is most unusual, and here we have an excellent example of a mistif stream — where the breadth of the valley is not consistent with the length.

Evidences of piracy, elbow captures, wind gaps are lacking, the cycle of erosion is young indeed, in winter a strong current hurls material of all sizes downward, in summer the all-but dry river bed is choked with débris. This mistif character is related to rock constitution in which the valley is excavated: where effusives outcrop, the stream has more difficulty in eroding its channel in breadth and concentrates rather in vertical corrasion; where pyroclastics outcrop, lateral corrasion is easier, the

valley opens out more in the upper and lower sections, the degree of fluvial erosion being least in the flatter upper section where the youngest rocks of the three sections outcrop.

Equally interesting is the trend of the Janela valley for it is the only significant one to run E-W for any considerable distance. This is believed due to the flows and ejectamenta of the Basal Complex being initially formed on longer, gentler slopes from the interior highlands westward, the valley trend and rock dips down in the same direction. Shortly before entering the sea, the Janela turns abruptly northwards. This is because the Pico da Roseira mass (elevation 834 m) formed of scoria cones, developed in this extreme N part of the coast, this vulcanism being of Pliocene-Early Quaternary age, and so later than the carving out of the main valley, so blocking the continued westward trend. The Rib. do Tristão, flowing to the W coast, is in good alignment with the Janela before the abrupt turning, the Roseira pyroclastic massif extending only as far S as the Tristão tributaries and does not interfere with the trends of the latter. The headwater tributary of the Tristão rises at an elevation of ca. 800 m and only some 1.5 km from the Janela whose elevation here is ca. 150 m. In the not-so-distant geological future one would expect river capture by the Tristão tributary to occur here and divert the Janela to the W coast.

In the major island of Madeira, some water divides between N and S flowing streams are remarkably narrow.

Below we indicate some examples of this (Mitchell-Thomé, 1979):

N-flowing streams	S-flowing streams	Horiz. distance between the headwaters, in m.	Height of divide, in m.
S. Vicente	Brava	200	1100
Porco	Soccoridos	100	1510
S. Jorge	Soccoridos	100	1625
Faial	Santa Lúcia	220	1575
S. Roque	Porto Novo	110	1380
Juncal	Machico	225	780

Many of the N-NE flowing tributaries of the Janela in its lower section rise within distances of 250 m from streams flowing to the SE, and equally striking is that at the E end of the island, S flowing streams have their sources within 200 m of the N coast, at the very brink of cliffs up to 100 m high above the N shore, yet these S flowing streams continue for up to 6 km to the S coast.

Obviously such very narrow watersheds and sources so close to opposing coasts betoken geologically imminent break-through the intervening land, with profound hydrographic changes. As N flowing streams have greater erosive ability, due to steeper and wetter slopes, one would assume that these would 'capture' the headwaters of S flowing streams, and in the case of the Ponta de S. Lourenço peninsula, the stronger marine erosion on the N windward side will erode the softer cliffs and thus tap the S flowing stream sources. N and NE windis occur during 67-80% of the year in Madeira, and average annual rainfalls amount to 1500 mm on the windward aspect. The writer has spoken to older inhabitants, who in turn could remember comments of their parents and grandparents,

which indicated that within periods of a century or so, headwater erosion in some of the N flowing streams was proceeding at a rate of 5 m extension and a lowering of the land by 30 cm. In the case of the Porco-Soccoridos streams, a mere 100 m distant at headwaters, land rising to 50 m between (to the E of Picoda Eirinhas) where an old inhabitant mentioned erosional changes that he, his parents and grandparents had witnessed, it was calculated that erosion was lowering the land at a rate of ca. 40 cm per century, and thus the 50 m elevation between the two sources could be obliterated in about 12 500 years — historically long but geologically very short. There is no doubt that Madeira proper, a high (maximum elevation 1862 m) and rather narrow island (maximum N-S breadth 22 km) will see some profound hydrographic changes in the imminent geological future.

CANARIES ARCHIPELAGO

By almost any criteria, the valley of the Barr. de las Angustias in La Palma must rank as one of the world's most imposing sights. This valley is formed within the Caldera de Taburiente, whose walls reach an altitude of 2626 m in Roque de los Muchachos, supreme point of the island. The valley trends SW, headwaters tributaries rising at elevations up to 2250 m. The NW rim of the caldera forms the towering El Time escarpment, trending remarkably straight, whereas the SE wall of the caldera is in general less impressive, more irregular, but attaining an altitude of 2321 m in Piedra Llana. The caldera (= valley) has a maximum breadth of 6.4 km, narrowing towards the SW where it measure a kilometre broad between 100 m contours. In general, the gradient of the main stream is 1 in 4.6. The gorge character of much of the stream course is striking, with many deeply incised meanders

resulting in a tortuous stream. There are neither roads nor habitations in this enormous deep valley, where many of the slopes are unscalable, due not only to their steepness but the ever-present danger of rock and scree falls. Theories vary as to how this great caldera was formed (Mitchell-Thomé, 1980), including 'craters of elevation', collapsed cauldron, and erosion, with/without mass gravitational movements. The El Time escarpment is taken to represent a great fault by Hausen (1969), whereas Middlemost (1970) has a prominent fault more or less coinciding with the stream course and extending well down the NE flanks of the caldera. No doubt faulting has played its role, collapse no less, but what is paramount is the role of erosion plus mass gravitational mass movements in hollowing out this remarkable valley.

In Gran Canaria, Bourcart (1935) first postulated an important fault transecting the island from NW to SE, with a throw of some 700-800 m to the NE, dividing the island into a Palaeocanaria to the W thereof and a Neocanaria to the E (Hausen, 1962), with older rocks outcropping in the former. Physiographically the two areas differ somewhat, Hausen, e. g. mentioning the «relatively old, stately mountain valleys» which widen along their courses to broad, flat mouths, have quite smooth longitudinal profiles, lacking waterfalls, cataracts — headwaters regions naturally differ in these respects — such being characteristic of Palaeocanaria, e. g. Barr. de Fataga, de Arguineguin, de Mogan, de Veneguera. In E-SE Gran Canaria, on the other hand, valleys have a younger appearance, very irregular longitudinal profiles, steep valley sides no less irregular, e. g. Barr. de Guayadeque (a magnificent 10 km long canyon occurs here), de Guiniguada, Tirajana. The whole terrain of western Gran Canaria has a different geomorphologic aspect — valleys more open, interfluvial regions not so sharp, hills more rounded, lower gradients to the sea, all indicative of a more advanced stage of

maturity, the relief here being taken to be per-barranco in age. In Neocanaria, valleys are narrower, more deeply incised, interfluvial ridges sharper, stream gradients steeper, gorge sections more common, all told, the relief is more rugged, irregular, and here relative youth in development holds sway.

The presence of this large fault and the major divisions of the island, as per the above, has been accepted by the majority of workers knowing the island, but in more recent times has been challenged, e. g. Fuster *et al.* (1968), Schmincke (1968) and the writer (1976). Though actually questioning the field evidence of the fault, the author does recognize a manifest physiographic distinction between Palaeocanaria and Neocanaria, and agrees with Schmincke who postulated a migration of eruptive centres in the island towards the E and NE with time, thus accounting for the prevalence of younger rocks (volcanic) and less advanced erosional modifications in the latter area. Fault or no fault, that indeed is the crucial question, but that valleys differ in the two districts is accepted, the eastern part having a younger geomorphological appearance.

Klug (1968) devoted some pages to Gran Canarian valleys, recognizing three generations and types of such: Kehltäler, oldest, wide, enclosed or residual valleys, in general basin-shaped — e. g. Barr. Temova, Tirajana; Muldentäler, shallow, very gently sloping outer parts, the stream itself in a narrow, deeper, inner valley, the whole of general basin-shape, e. g. Barr. Tenoya, Chira; Kerbtäler, steep-walled, onetime eroded valleys, common in the W and SW, e. g. Barr. Tazarte, Tavrito. (Examples quoted above are by the author, not Klug). Fig. 9a, adopted from Klug, shows these three types of valley, Kerbäler being youngest. Klug thought that the oldest phase of valley formation was during M. Miocene-L. Pliocene times (vulcansim in the island dates from pre-Vindobonian (but Miocene) to late Quaternary); where the relief is milder

in the N and E flanks, Kehltäler and Mullentäler were later developed in late Pliocene-Quaternary times, when base-level was constant, whereas in the W and S, where most imposing cliffing occurs, due to profound variations in base-level, Kerbtäler formed. It is thus seen that Klug is not in agreement with Hausen as to valley features in the two major sectors, though both agree in valley differences of form in said two sectors. The writer must confess he finds it most difficult to believe in pronounced base-level variations in the older meogene in contrast to constant base-level in younger Neogene-Quaternary times — indeed, the opposite seems more likely. Very noticeable in Gran Canaria is the very rugged, high-cliffed W and NW coasts contrating with those of the NE, E and SE which are smoother in outline, flatter and where extensive fluvial and deltaic sedimentation has occurrend, such sandy beaches attracting the tourists rather than the more stern, pebbly, cliffed coasts elsewhere.

Hausen (1962) has discussed in some detail the Barr. de Tejeda, its drainage basin and the Tejeda caldera within which the valley lies. The main stream is some 25 km long (Barr. de La Culata higher up — a common trouble with so many Portuguese and Spanish streams in these islands is that they change their names in various sections thereof) and begins at an elevation of some 1750 m, the drainage basin measuring about 85 km^2. In all aspects, this is the major valley of Gran Canaria. Most of the drainage is through the caldera, largest in the island — if we exclude the «Old Caldera» of Schmincke & Swanson, 1966; Schmincke, 1968; McDougall & Schmincke, 1976-77 — with a perimeter of 36 km and up to 13.8 km from rim-to-rim (Mitchell-Thomé, 1980).

The valleys is not one continuous gorge, for it receives several significant tributaries, Barrancos de Chorrillo, de Carranzal, de Siberio from the S side, whereas much less impressive and smaller valleys enter from the N side.

Vigorous erosion plus powerful mass gravitational movements result in height differences of 1000 m in short transverse distances. Hausen argued that the entire drainage network was developed chiefly in sub-Recent times. Where the water gap occurs, in the vicinity of S. Nicolas, the stream flows through a 4 km long gorge, where unscalable slopes lead up to heights as great as 1400 m. This gorge is clearly an antecedent feature, the canyon section offering an outlet spillway of a pre-caldera basin, perhaps forming a lake, as per Hausen. He further claimed that: «The downcutting of the canyon has gone on at the same pace as the erosion inside the Tejada basin behind it, all the gorges there having adjusted their bottoms to this (water gap) gorge». The limits of the caldera do not coincide exactly with the Tejada drainage basin, the latter being considerably greater in circumference. In Gran Canaria, this caldera drainage basin and valley form the outstanding landscape feature of the island.

In Tenerife are three valleys which have aroused discussion, the Valles de Orotava, de Guimar and de La Laguna. The first is open to the N coast, descending from the Pedro Gil axial spine from heights of 2300 m. This valley (it is rather a large basin-shaped hollow) is some 12 km in length and ca. 9 km broad for much of this length, bounded to E and W by near-vertical scarps, such that the head region is arcuate (Hausen, 1955; Ridley, 1971). The area is densely peopled, especially in the lower northern sector, with its well-know gaudy tourist resort of Puerto de La Cruz, the lower valley area being the premier banana plantation part of the island. The coastal area between the embracing scarps, is slightly convex, low and sandy, contrasting with high cliffed coasts E and W thereof. The valley rises gently to the S, with few breaks in slope, but at approx. 1500 m there is a rapid slope increase to heights exceeding 2000 m. In 1955, Hausen thought the scarps might be of tectonic origin, presumably

fault-line scarps, but later (1961, 1970, 1971) was less sure of this concept, referring rather to the role of mass gravitational movements. Bravo (1962) considered the fanglomerates of the valley area also to a similar cause (as also in the Guimar valley), and Fuster *et al.* (1968) were more inclined to see great landslides as the cause of the valley. But in 1952 and 1954, Bravo had also mentioned that there had maybe been large inroads of the sea — ria-type development — as the chief cause of both the Orotava and Guimar valleys, and Klug (1968) was quite sympathetic to this idea, a concept which actually dated back to Rothpletz (1889). Ridley (1971) unabashedly favours a volcanotectonic origin, though he acknowledges a minor role for landslides, etc. He believed that here we have a caldera-collapse structure, consequent upon the draining-away of magma from a central area beneath a fissure zone towards the flanks of the volcanic complex.

The Guimar Valle descends SE from Pedro Gil. As per Ridley (op. cit.) it is 10 km long, 6 km broad near sea level but broadens to 8 km at the valley head. Very abrupt scarps enclose the valley to the NE and SW, the latter attaining heights of 600 m and continuing for 7 km to the coast. Like Orotava, the valley head is a large arcuate feature, concave towards the SE. The valley floor lowers itself towards the SE in a series of giant steps over a distance of 4.5 km, at which point there is a pronounced break in slope before descending to the broad, smooth coastal plain. Again Hausen (1955) favoured a tectonic origin for the valley initially, but as before, he later was inclined to place greater emphasis on mass gravitational movements. We have remarked above that Bravo and Klug referred to marine incursiones here as at least partially responsible for the valley, whilst Fuster *et al.* deny all tectonism. As with the Orotava valley, Ridley appeals to a volcano-tectonic origin.

Extending NW from the island capital of Santa Cruz is the La Laguna valley which separates the rugged, mountainous Anaga peninsula from the NE extremity of the Pedro Gil dorsal spine. The valley bottom rises to an elevation of 550 m above SL, sloping both towards the SE and the NW. Higher, steeper terrain, more pronounced relief of the Anaga region borders the N side of the valley, whereas to the S, land rises more gently to lesser heights, and thus transversely, the valley is topographically asymmetrical. W and NE of the university town and religeous centre of La Laguna, at the summit of the cross valley, lies an area 10 km in length and up to 4 km broad of distinctly flatter terrain where only soft, friable arenaceous sediments occur at the surface, and here the international airport of Los Rodeos has been constructed. Whether this through-valley is of tectonic or landslide origin has not been settled, nor, in fact, been given much attention. Noticeable is the relatively abrupt and sinuous rise up to the Anaga heights, which indeed may represent an eroded fault scarp, hence a fault-line scarp, and indeed Mingarro (1963) did postulate a great fracture along most of the N side of the valley. On the other hand, Blumenthal (1961) believed that faults limited the valley to N and S, generally parallel to the valley, and extending right across the terrain from the W to the E coast. As geomorphological studies are all but lacking of this significant valley, its origin is uncertain at this time.

CAPE VERDE ARCHIPELAGO

In NE Santo Antão, the Rib. Grande (main channel ca. 13 km long) flows generally northeastward, parallel to the trend of the northern coast and at a mean distance of 3.5 km therefrom. Between the valley and this stretch of coast, land rises to 892 m, with an abrupt southward

slope and only two-three small tributaries flowing down. On the S side of the Grande valley, land slopes upward much more gently to heights of 1568 m, and here there is a relatively dense network of valleys heading N and NE. The Rib. Grande and its chief tributary, the Rib. Despenhadeiro, have somewhat curving paths, fronted by the prominent mountain wall to the N. Here we have a fault striking parallel to this part of the N coast, whereby an upraised block, tilted to the N, between the main valley and the coast was formed. The N wall of the valley is a fault scarp, showing also evidences of becoming a fault-line scarp, with a slope of ca. 30° (Mitchell-Thomé, 1960). (When measured in the field, slopes are invariably less than one would imagine, and when measured from contoured maps, we must note that it is the sine of the angle and NOT the tangent that must be recorded) (Mitchell-Thomé, 1977). In this NE corner of Santo Antão, Bebiano (1932) noted evidences of uplift, with river terraces at the mouth of the Rib. Grande now 10-20 m above SL, and at various places as far up the main valley as 8 km the writer has observed such terraces as high as 28 m above SL. A fault is also surmised to trend approximately parallel to the coast — the N edge of the fault block — such that the block is taken to have been upraised, horst fashion, between the two faults. Down the N-tilted block, many small, deep, canyon-like valleys descend down to the coast, most of which leap over cliffs as high as 300 m, and here and there on flatter coastal terrain, smaller marine abrasion platforms are found, e. g. that at Ponta do Sol, 3 m above SL, and in this coastal sector are marine terraces now 10-25 m above the sea. (The N coast of Santo Antão has a wild, rugged, forbidding, lonely aspect, with few habitations or villages). The fault paralleling the Rib. Grande to N has blocked the N flowing streams and diverted them into a NE flowing Grande. We would also note that the Grande

valley is remarkably broad and level throughout its NE-SW section — 300-400 m broad in places.

In Boa Vista is the longest stream in the archipelago, the Rib. Rabil, some 25 km in length, and only in Tenerife are there two-three longer streams, but Tenerife is three times the area of Boa Vista. The Rabil has also the largest drainage basin in the archipelago, 140 km^2, almost 23% of the island. Throughout the greater part of its course, this is a broad, shallow valley, the stream rising at an elevation of 315 m, only some 9 km from the E coast, and following a circuitous route to the W coast. Small-scale meandering is not noticeable, but on a larger scale this becomes more prominent as the coast is approached. There being flowing water for only a microscopic time of the year, the dry valley is littered wih débris and shows much anastomosing. The valley begins a mere 400 m odd from a tributary valley of the Rib. Renca, which also trends S before turning to the NE. Into the Renca comes the Rib. Morro Negro valley, which commences only 700 m from the E coast, but instead trends westward. The Rabil thus makes a long detour of 25 km to the W coast, whereas 9 km would take it to the E coast. The reason(s) for such a detour are note clearly apparent either from maps or field studies. The youngest volcanic phase of submarine pillow lavas and subaeriel lavas (Chão de Calheta Formation of Serralheiro *et al.* (1974)), likely of late Pliocene and/or Early Quaternary age partially forms the topographic axis running N-S here, and it may be that this more recent phase of vulcanism expelled forth lavas which interfered with the prior drainage network. This vulcanism, the most important in the island, is seen only in the peripheries of Boa Vista, especially the SW, S and SE. The absence in the interior of the island might have been due, as per the above authors, to «les édifices volcaniques ayant peut-être existé étaient trop modestes pour pouvoir résister à l'érosion». In the island interior, the

Old Internal Eruptive Complex outcrops, comprising both extrusives and intrusives, a tougher, more resistance ensemble of rocks which extends southwards towards the Calheta Formation, with extensive alluvial deposits in between. How old the Complex might be is uncertain. The eastern islands of Sal, Boa Vista and Maio are generally conceded to be the oldest in the archipelago, and Malm is recognized in the last mentioned. It is possible that the Complex dates from the L. Cretaceous, perhaps Neocomian. Granting that the Complex comprises rocks more resistant to erosion than the Calheta rocks, yet most of the lower half of the Rabil valley is excavated through these old Complex rocks, and indeed in places here the valley is only ca. 150 m broad, even less in places, and well incised into the rocks. One wonders if this lower part of the Rabil is not perhaps contemporaneous with the Complex igneous events. The present annual average rainfall of Boa Vista is only ca. 275 mm, and all streams merely flow for very short periods after the infrequent rains. Yet in the Complex terrain, the Rabil has managed to erode its way through these more resistant phonolitic, syenitic, basaltic rocks, and maintain its route westwards to the coast. Surely then in the past, rainfalls must have been greater than at present, where perhaps 360 days pass annually without a drop of rain, and in the remaining 5 days, perhaps a few short, severe downpours. We must confess that the cause(s) of this long Rabil detour escapes us. (It might be of some significance — but in what way? — that Mendes-Victor (1970) remarked that as regards the Bouguer anomalies Boa Vista shows the most complicated picture of any Cape Verde Island).

In Fogo the last eruption occurred in June-August, 1951, when extensive lava flows brimmed over the eastern slopes of the great caldera, in many instances continuing right down to the sea. (This eastern slope averages 25°, with the central cone of Pico, 2829 m, only 6.25 km from

the E coast). Of distinct interest here in eastern Fogo is that the lava outpourings of the 18th and 19th centuries and the last event did NOT take advantage of stream valleys in their downward courses but rather preferred to utilize inter-valley terrain. Thus the short, steep, deeply entrenched valleys down to the E coast do not display lavas of these later eruptions but only lavas of previous times. The 18th, 19th and 20th century outpourings comprise largely rocks of basaltic, basanitic and limburgitic composition, i. e. basic-ultrabasic type rocks, which are typified by having less viscosity than acidic type rocks, hence able to flow further and quicker, hence not the same need to seek out valleys, depressions in gaining momentum.

Brava, the smallest inhabited island, 64 km^2, has several valleys which have most impressive gorge sections. In some, e. g. Rib. Fundo do Cachaço (ca. 3.5 km long) it is the middle section; in the Rib. do Matim (ca. 3.3 km long) it is the lower half of the valley which is canyon formed; in a small, unnamed valley heading down from Figueirinho (ca. 1 km in length) it is the upper half which lies between canyon walls. (No less are there one or two areas of higher land bounded on two-three sides by almost vertical sides, having horst appearances, lying inland from the coasts). The first two valleys have eroded the gorge sections in phonolitic, syenitic and pyroxenitic rocks, whilst the third valley and upper reaches of the other two are carved into pyroclastics interbedded with flows, both of phonolitic type. What is notable in such types of valleys is that the canyon occurrences are restricted to the extrusive-intrusive terrain rather than the more loose and friable pyroclastic areas, as per outcrops, though intercalations of flows and pyroclastics is the common feature. Some of these gorge sections are up to 2 km in length and up to 250 m in width; some, e. g. the Cachaço valley, have linear walls and arcuate walls at the canyon head; others have

scalloped brinks, moulded to the contours. Those valleys with linear gorges are fault controlled — the upper Matim stream flows along a fault trench for some 1.5 km before plunging ca. 300 m into the gorge basin. The scalloped edges of the Cachaço gorge section comprise ankaratrites rocks, whereas down in the canyon intrusives are outcropping all the way to the coast. Throughout this small island, the relief is extraordinarily strong, coastal slopes are unusually steep, valleys very deeply entrenched, e. g. Rib. Fajã de Água, several perfectly circular deep craters are dotted here and there, and everywhere one is aware of the powerful effects of fluvial and marine erosion. The above valleys with their canyon section are small features, admitted, but nevertheless most impressive when viewed in the field, and all told this island, with its delightful shade and greenness at higher elevations and stark, barren coasts, affords both pleasures and interests to the visitor.

In southern Sal a unique feature is present. The small valleys of the Ribeiras Palapa and Fonte de Vaca, each only ca. 3.5 km long, rise at an elevation of ca. 38 m, one valley heading NW, the other, SW. During a week of unusual heavy rainfall for the island (average annual rainfall is only 102 mm, driest island in Macaronesia), it was noted that on some such days, headwater sheet flows headed for the Papala depression, at other times, for the Vaca valley, and during a two hour stay here when heavy rains were falling (everyone on the island is thrilled to see rain, the author no less!), it was noted that the thin sheet flows sometimes trended towards the Palapa valley, sometimes towards the Vaca valley, which course to take seemingly a purely fortuitous matter, the waters taking one trend or the other as a matter of chance, laws and regulations entirely suppressed. Seldom do we find near-source waters vacillating in this manner, uncertain which route to take. A classic and more striking instance is in Venezuela, where the headwaters region of the Orinoco some-

times has streams flowing N and NW and so to the Atlantic, and at other times, these same waters prefer instead to turn SW and S to flow into the Amazon.

Lastly we would refer to Maio, where a series of valleys trending northwestward, terminate in an enclosed basin — Terras Salgadas. This salt-encrusted area, from 2-4 m above SL, comprises river alluvium, beach sands, actual and fossil dunes, comminuted calcareous sands, scattered pebbles, cobbles, etc. Except where the valleys enter the basin from the SE, all the borders of the latter are formed of acive dunes. These valleys begin at elevations as high as 250 m, and during times of short, intermittent rains, they are actively engaged in eroding as well as transporting. The streams at one time continued to the sea but now dunes intervene. Dominant winds are from the NE and N, often strong and nearly always very gusty. Beach sands have been piled up into dunes, the dunes are still «on the march», and thus have blocked the exits of the NW flowing streams. At times of rain, the streams pour their waters into the basin, intense evaporation takes place resulting in this most barren depression.

CONCLUSION

None of the principal islands of Macaronesia are large, ranging in area from 17 to 2058 km^2, no valleys have great length, about 27 km being the maximum, only the Rib. Rabil in Boa Vista has the drainage basin more commanding proportions, 140 km^2. On the other hand, maximum heights relative to island areas, are indeed impressive, even for some islets. Relatively small island areas, short valleys, small drainage basins, great height, strong relief, imposing cliffed coasts typify volcanic islands such as we have here.

The initiation and development of valleys are primary the work of rivers and streams, and here the roles of climates pertaining, past and present, rock constitution, structures, tectonics, vulcanism, eustatism, isostasy, all enter into the geomorphological evolution of said valleys, and of course, the all-pervading factor of Time.

The valleys remarked upon here all show some less common or unexpected features, in each case, some factor(s) have manifested themselves so that the more 'normal' characteristics have been interfered with. But realizing the complex interplay of all the circumstances involved in valley development, one might well pose the question: What is the 'normal' evolution of a valley?

These archipelagos have caught the interest of specialists in vulcanology, igneous petrology, petrochemistry, petrogenesis, but by comparison, other geological facets have been given little study. Nowhere is this paucity more evident than in geomorphologic investigations, where publications treating entirely on such of these islands-archipelagos, can almost be counted on one hand — agreed of course, many papers, books, treat of such *en passant*.

The late Professor Cotton, that highly gifted student of geomorphology wrote a fascinating book (1944) regarding the landscape features of volcanoes and volcanic phenomena. As yet, as far as the writer is aware, no one has compiled a tome of smaller islands from a similar standpoint. It would provide an interesting study to combine these categories dealing with the landforms of volcanic islands, especially under the climatic regimes pertaining, such as ir found in Macaronesia. The scholar who would be aroused to make such studies could be assured of ample interests, pleasant climatic conditions and superb scenery, perhaps the finest in the world, in these Macaronesian islands which long have cast a spell over adventurers, travellers and scholars.

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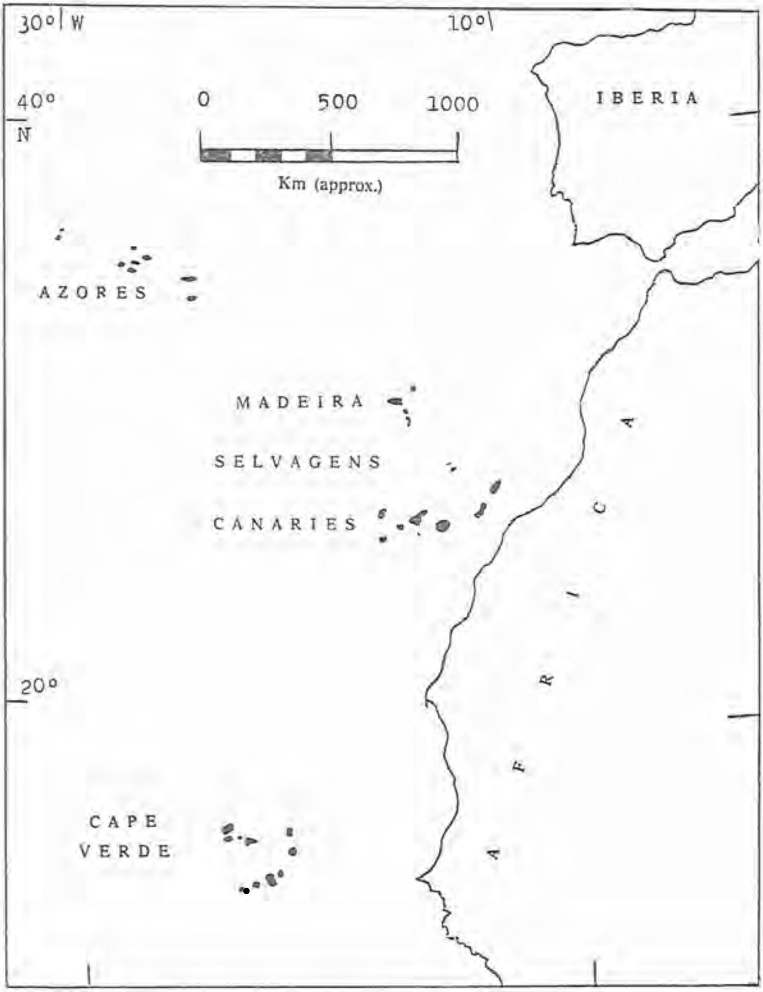


FIG. 1 — *MACARONESIA*

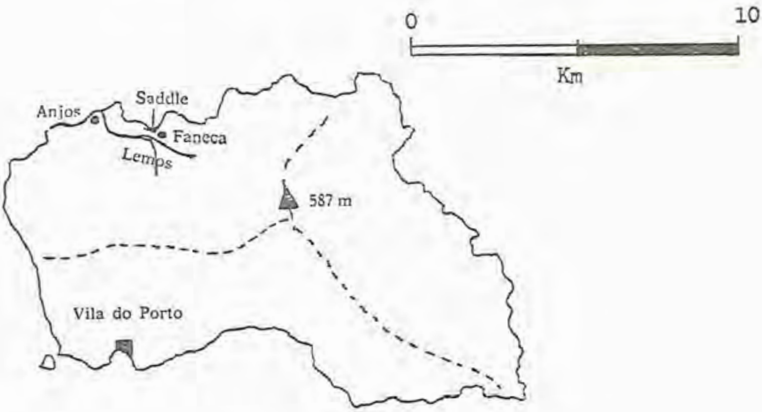


FIG. 2 — *SANTA MARIA*

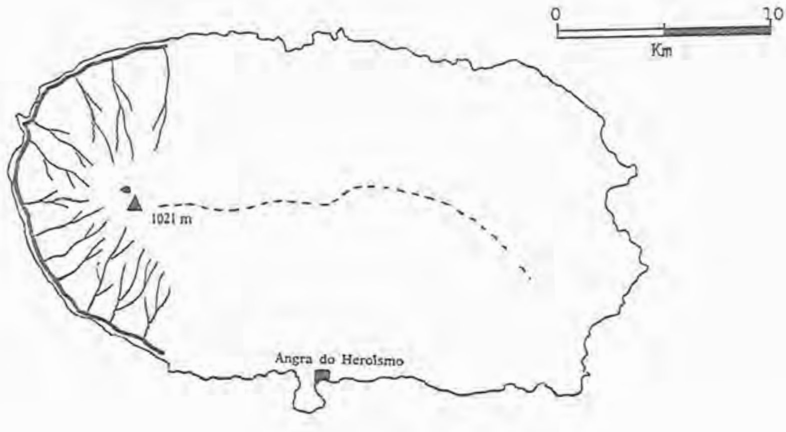


FIG. 3 — *TERCEIRA*

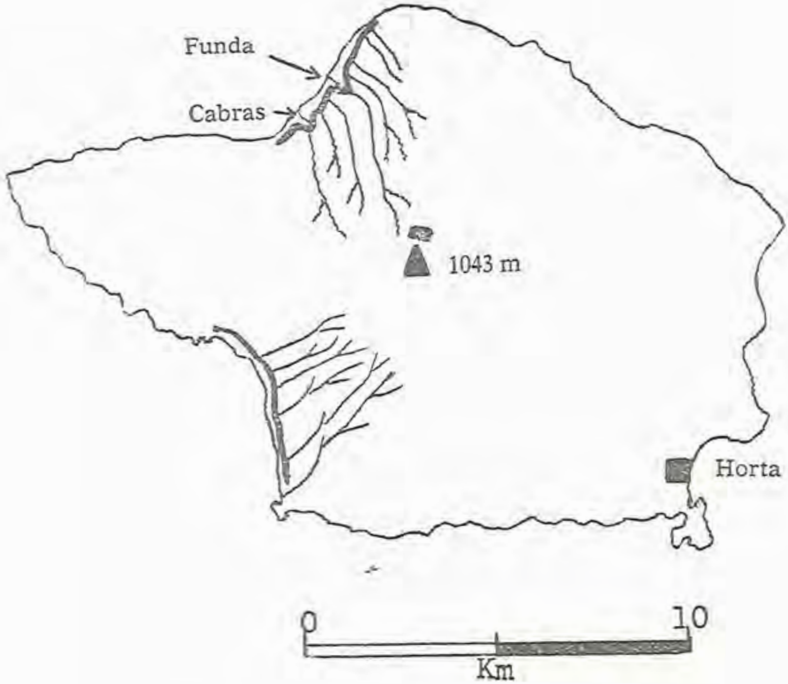


FIG. 4 — *FAIAL*

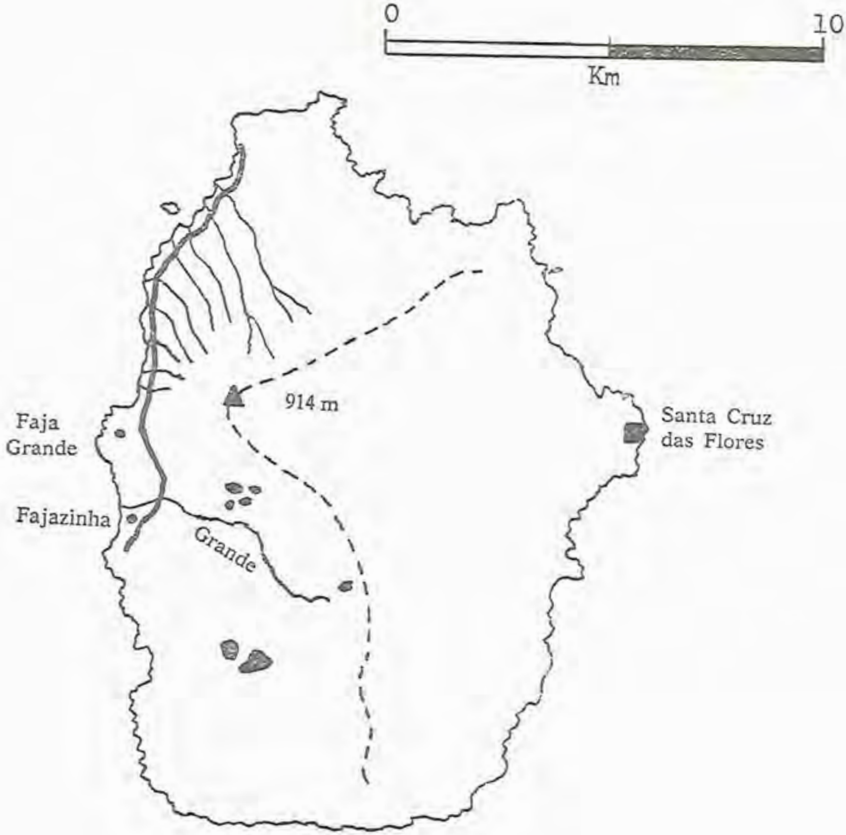

0
10
Km
914 m
Faja
Grande
Fajazinha
Grande
Santa Cruz
das Flores

FIG. 5 — *FLORES*

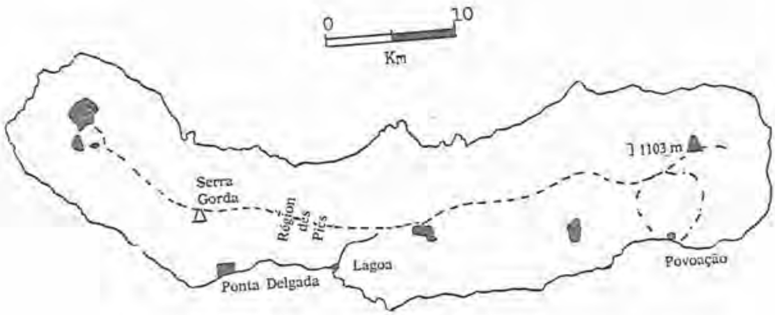


FIG. 6 — *S. MIGUEL*

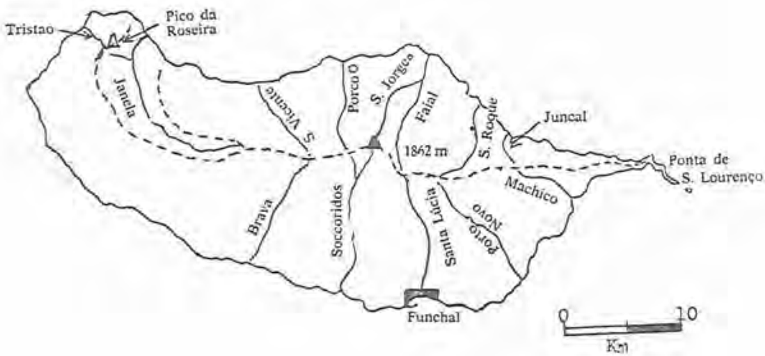


FIG. 7 — *MADEIRA*

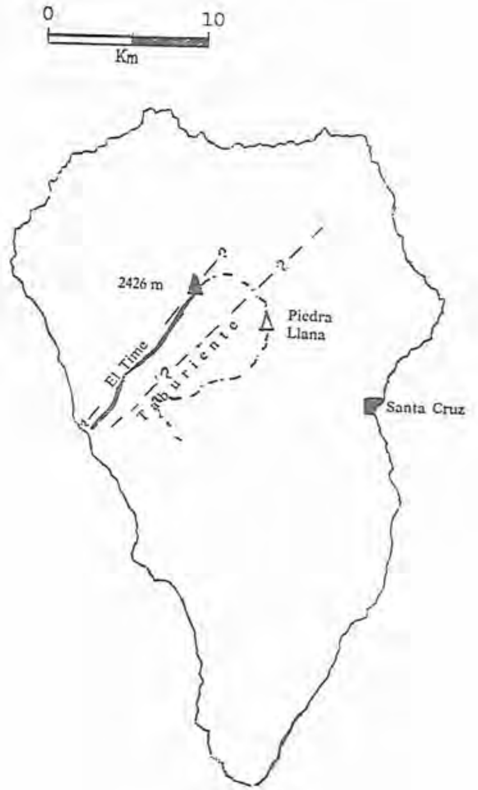


FIG. 8 — *LA PALMA*

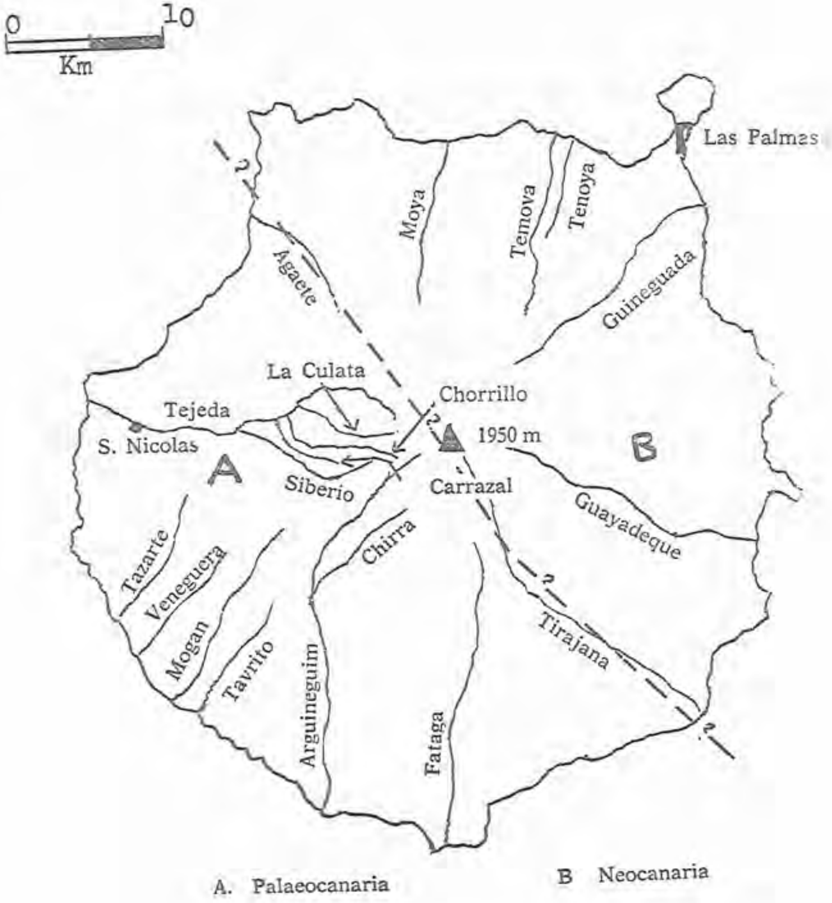


FIG. 9 — *GRAN CANARIA*

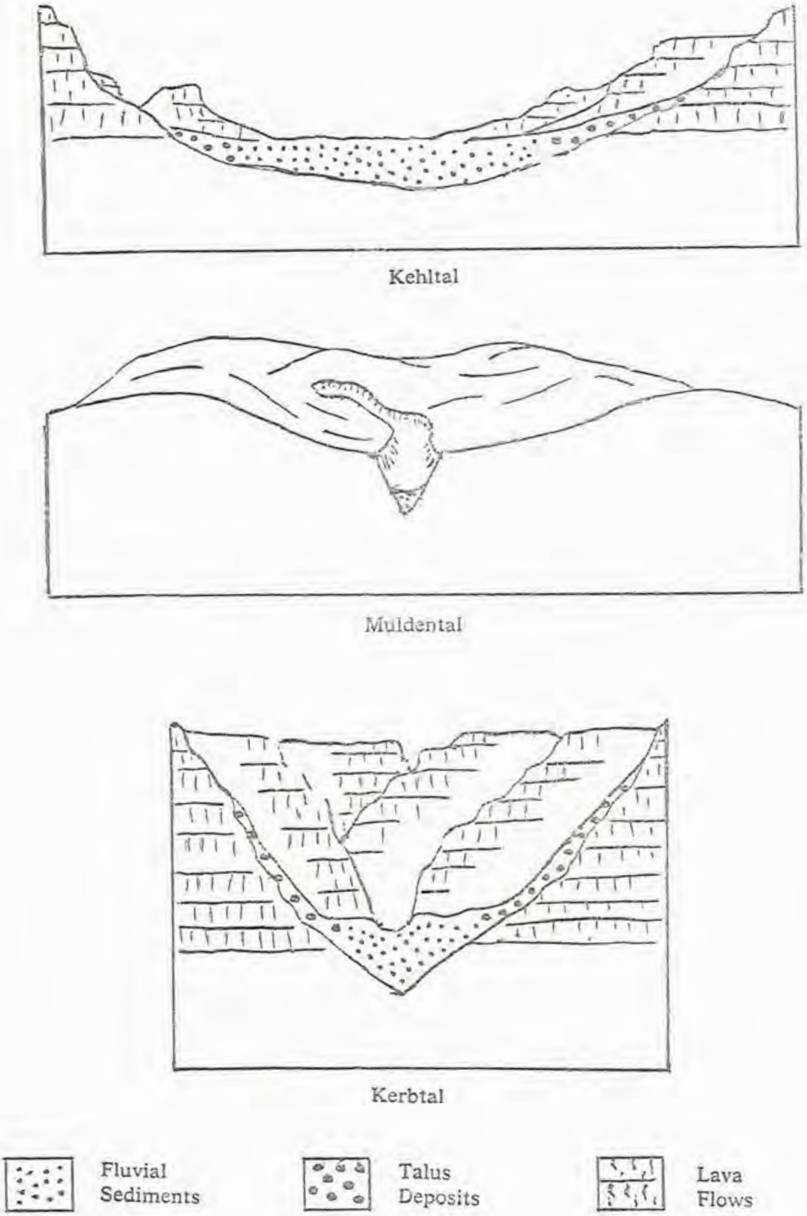


FIG. 9a — *VALLEY TYPES IN GRAN CANARIA*
(Modified after Klug, 1968)

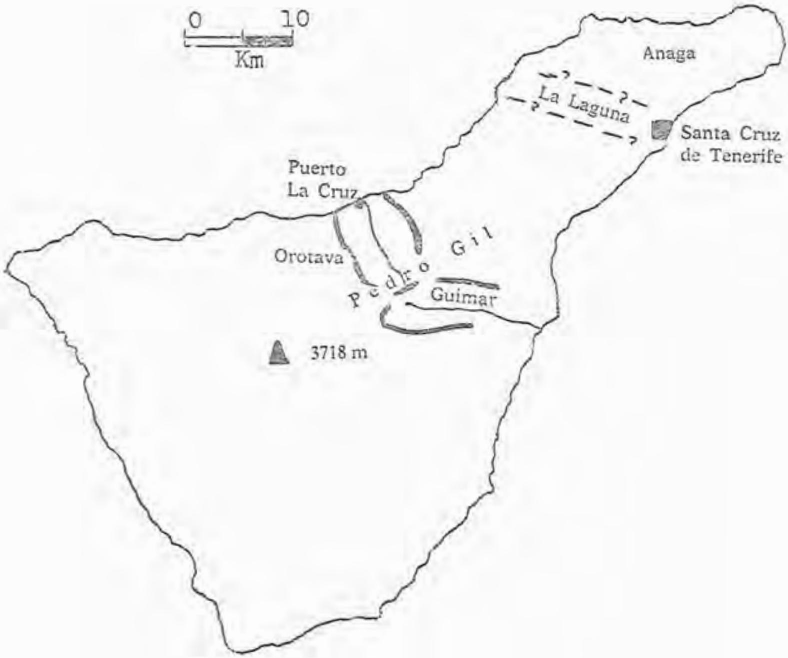


FIG. 10 — *TENERIFE*

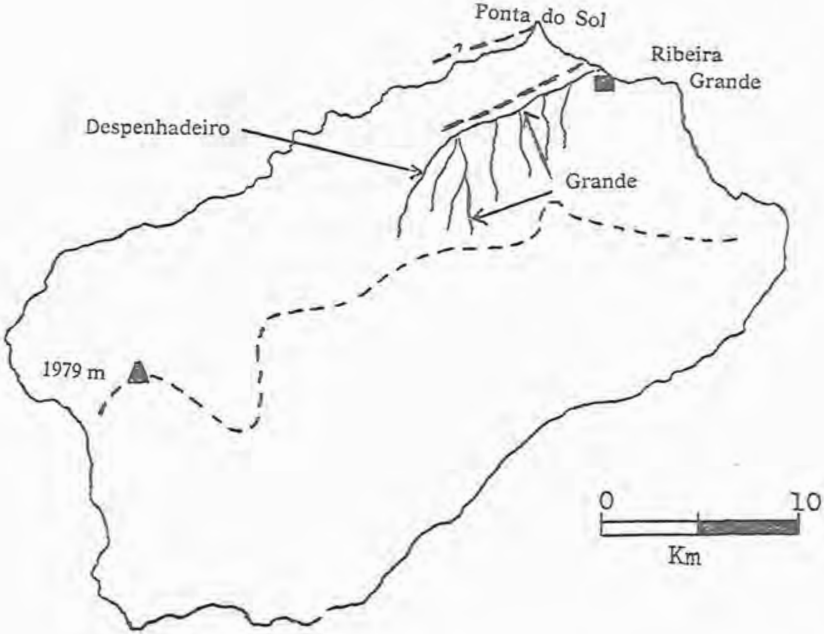


FIG. 11 — *SANTO ANTÃO*

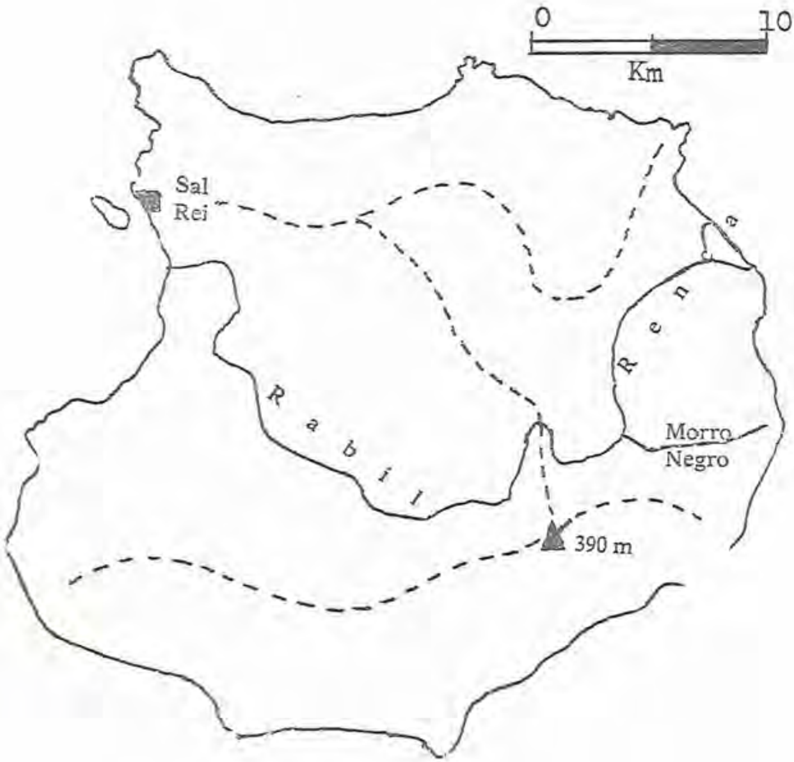


FIG. 12 — *BOA VISTA*

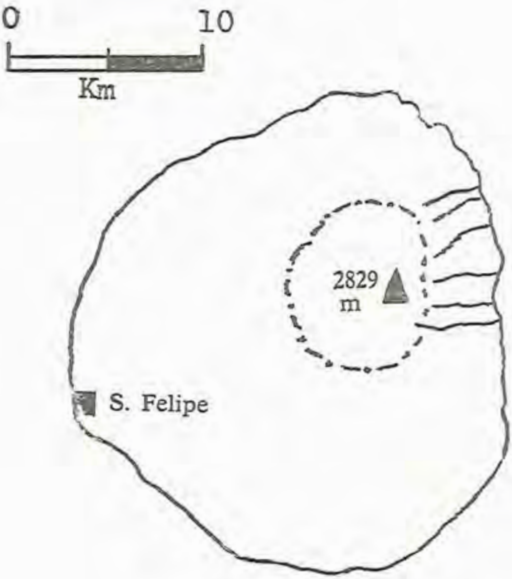


FIG. 13 — *FOGO*


0
5
Km
Nova
Cintra
Feja de
Água
Figueirinho
Matim
976 m
Cachaço

FIG. 14 — *BRAVA*

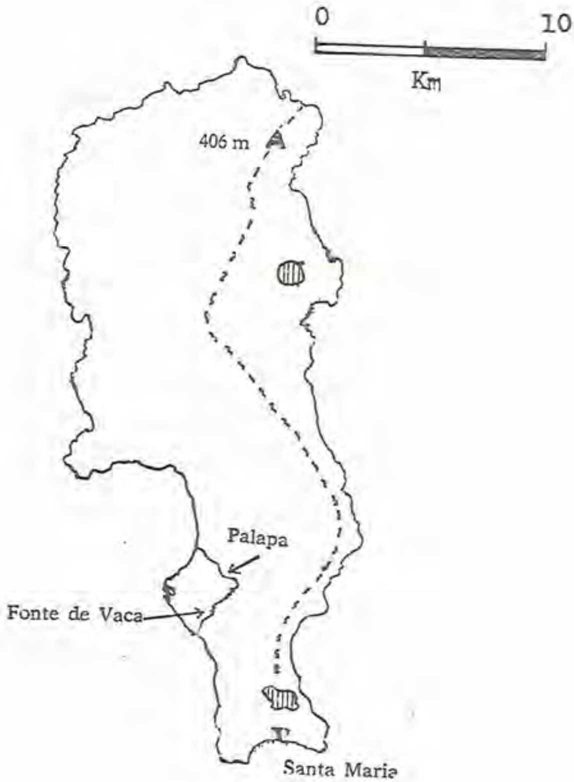


FIG. 15 — *SAL*

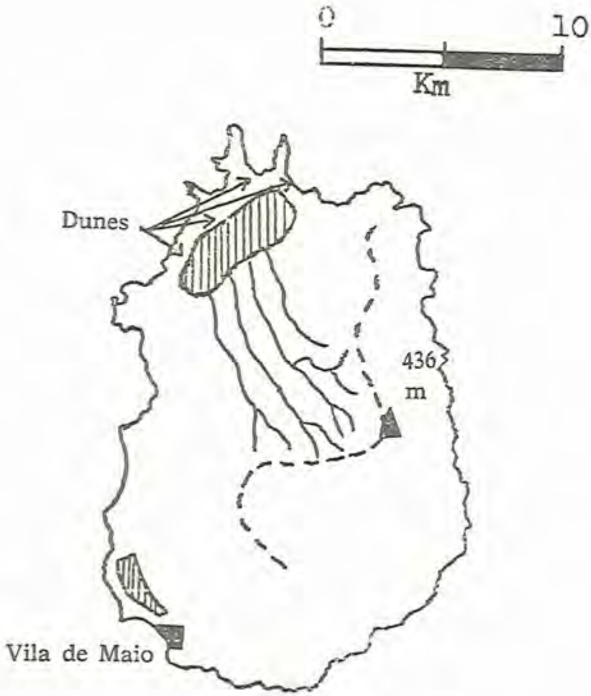
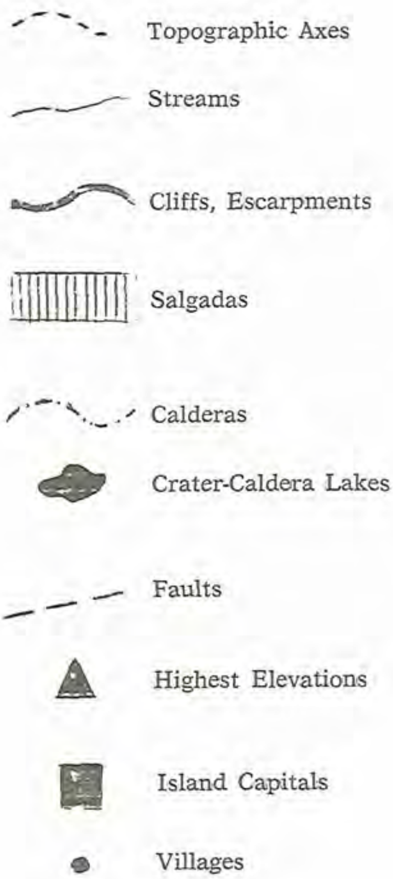


FIG. 16 — *MAIO*



LEGEND FOR MAPS 2-16