LA FAUNE TERRESTRE
DE L'ILE DE SAINTE-HELENE

(Première partie)

II. — GEOLOGICAL HISTORY OF SAINT HELENA IN RELATION TO ITS FLORAL AND FAUNAL COLONIZATION

by

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ABSTRACT

Saint Helena is truly oceanic in nature and is built up entirely of volcanic and very rare organically-derived rocks. The oldest sub-aerial rocks on the island have been dated as 14.3 ± 1.0 million years old. Two volcanoes built up the island over a period of more than seven million years, and volcanic activity finally ended approximately seven million years ago. The most favourable dates when volcanic activity might have permitted extensive floral and faunal colonization of the island were 11.4 ± 1.0 million and approximately 9.5 ± 1.0 million years ago. Evidence from the volcanic products demonstrates that the South-East Trade winds were dominant throughout the growth of the volcanoes and into the Plio-Pleistocene. It is likely that during the Pleistocene glaciations wind velocities were greatly increased and were probably responsible for major modifications in the flora.

INTRODUCTION

The island of Saint Helena forms the upper levels (approximately 825 m) of a volcanic pile rising more than 5 km above the ocean floor. The nearest continental landmasses are 1,800 km to the east (Angola), and 3,000 km to the west (Brazil). The nearest neighbouring islands are Ascension, 1,200 km north-westerly, and the Tristan da Cunha group 2,100 km to the south. Saint Helena is therefore characterized by its remoteness, and appears typically oceanic in terms of its bathymetry, geochemistry and geographic setting.

All of the rocks that form the two sub-aerial volcanoes building up the island belong to the alkali olivine - basalt - trachyte - phonolite assemblage (BAKER, 1969).

The geology of the island has been described in detail (BAKER, 1968a), but is not yet published, and a geochronological investigation of the volcanic activity has been carried out using the potassium-argon method (BAKER, GALE and SIMONS, 1967). The aim of this chapter is to discuss in broad terms the volcanic history of the island with reference to the absolute dating of the various stages of its growth and their bearing on the colonization of the island by plant and animal life.

GEOLOGICAL HISTORY

Saint Helena is built up of two essentially basaltic shield-volcanoes. The older north-eastern mass, with its centre in the region of Knotty Ridge, is smaller and less complex than the south-western volcano centred in Sandy Bay (map 2). The volcanoes are built up predominantly of basaltic lava flows and scoria erupted from major fissure concentrations now seen as extensive dyke swarms in the highly eroded central regions. Lavas of intermediate composition are extremely rare in the north-east (trachybasalt), but are more common in the south-west (trachybasalt, trachyandesite). Parasitic activity on the flanks occurred throughout the growth of both volcanoes, although it is markedly more common in the south-western mass. In both shields lava flows may be separated by thin, well-bedded ash layers, frequently reddened by baking from the overlying flow. Local and widespread erosional surfaces were commonly developed in both volcanoes throughout their growth, but no soil horizons were found separating lava flows in either volcano.

THE NORTH-EASTERN VOLCANO

The stratigraphic divisions and absolute ages of dated rocks of the north-eastern volcano are shown in Figure 5. All dates have their errors quoted at a 95 % confidence level. The oldest rocks are highly altered, fragmental, basaltic rocks largely replaced by chloritic minerals and carbonates. They occur in the core of the volcano attaining an elevation of nearly 400 m above sea-level in Knotty Ridge (map 2). The shield-forming basaltic rocks rest on these fragmental rocks with a sharply defined, but poorly exposed boundary. One of the most distinctive features of this boundary is the contrast in numbers of dykes above and below it — dykes cutting the older fragmental rocks are more abundant by a factor of approximately ten than those cutting the sub-aerial rocks of the shield above. The boundary at the base of the shield therefore marks an erosional surface of considerable magnitude.

These fragmental rocks display a number of features not seen elsewhere on the island, and their markedly different lithology reflects a fundamental difference in origin of the rocks above and below the unconformity :

- i The breccias are unsorted, of very variable size grade (never exceeding 0.5 m) and only locally bedded.
- ii Many dykes cutting the breccias are sinuous and display thin glassy margins. In the sub-aerial pyroclastic rocks of the south-western volcano dykes are strongly linear and do not display glassy margins.
- iii Dykes display no contact effects against the breccias, whereas elsewhere on the island dykes redden the pyroclastic rocks that they intrude.

iv The early pyroclastic rocks in the core of the south-western volcano, although subjected to an equivalent depth and length of burial, are largely unaltered (chloritic minerals are exceedingly rare and only very locally developed) and vesicles contain abundant zeolites (not observed in the breccias of the north-east).

v Opaque oxides in fragments of the breccias often display skeletal textures typical of quench basalts.

The unique characteristics of these oldest fragmental rocks of the island, and in particular the widespread chloritic alteration, believed to reflect the original presence of abundant glass, suggest that these rocks may be submarine in origin. This inference is strongly supported by the characteristics of many of the dykes which intrude them, which with their glassy margins and absence of contact effects, would appear to have been emplaced in a saturated environment.

Field evidence suggests that part, if not most, of the uplift of these breccias to their present elevation occurred during the early growth of the sub-aerial shield volcano. If this is the case the initiation of shield-building activity (14.3 $\pm$ 1.0 million years ago) may be taken as coincident with the origin of Saint Helena as an island. The earliest terrestrial life-forms could not therefore have arrived on the island before Upper Miocene times.

The sub-aerial part of the north-eastern volcano (approximately 800 m of basaltic lavas and pyroclastic rocks) attained a maximum height of between 1,200 m and 1,300 m above sea-level. One major and several minor erosional unconformities are exposed in the sequence. At approximately the same time as shield-building activity ceased in the north-east (11.4 $\pm$ 1.0 million years ago) activity in the south-west commenced.

The youngest rocks of the north-eastern volcano are scoriaceous basaltic extrusive rocks, of limited extent and thickness, exposed on the east side of Rupert's Valley. These rocks were probably erupted during a period of quiescence of the south-western volcano between nine and ten million years ago (Fig. 5). (The rocks in fact filled a valley belonging to the radial drainage pattern of the south-western volcano, and preceded the extrusion of lavas of the Upper Shield of that volcano.)

THE SOUTH-WESTERN VOLCANO

The stratigraphic divisions of this younger and volumetrically larger volcano are summarized in Figure 5 together with the absolute ages of dated rocks. The main feeder zone of the volcano is located in the Sandy Bay District where an impressive NE - SW trending dyke swarm is exposed. Each of the three major divisions of the volcano (Lower, Main and Upper Shields) was built up by a characteristic mode of extrusive activity.

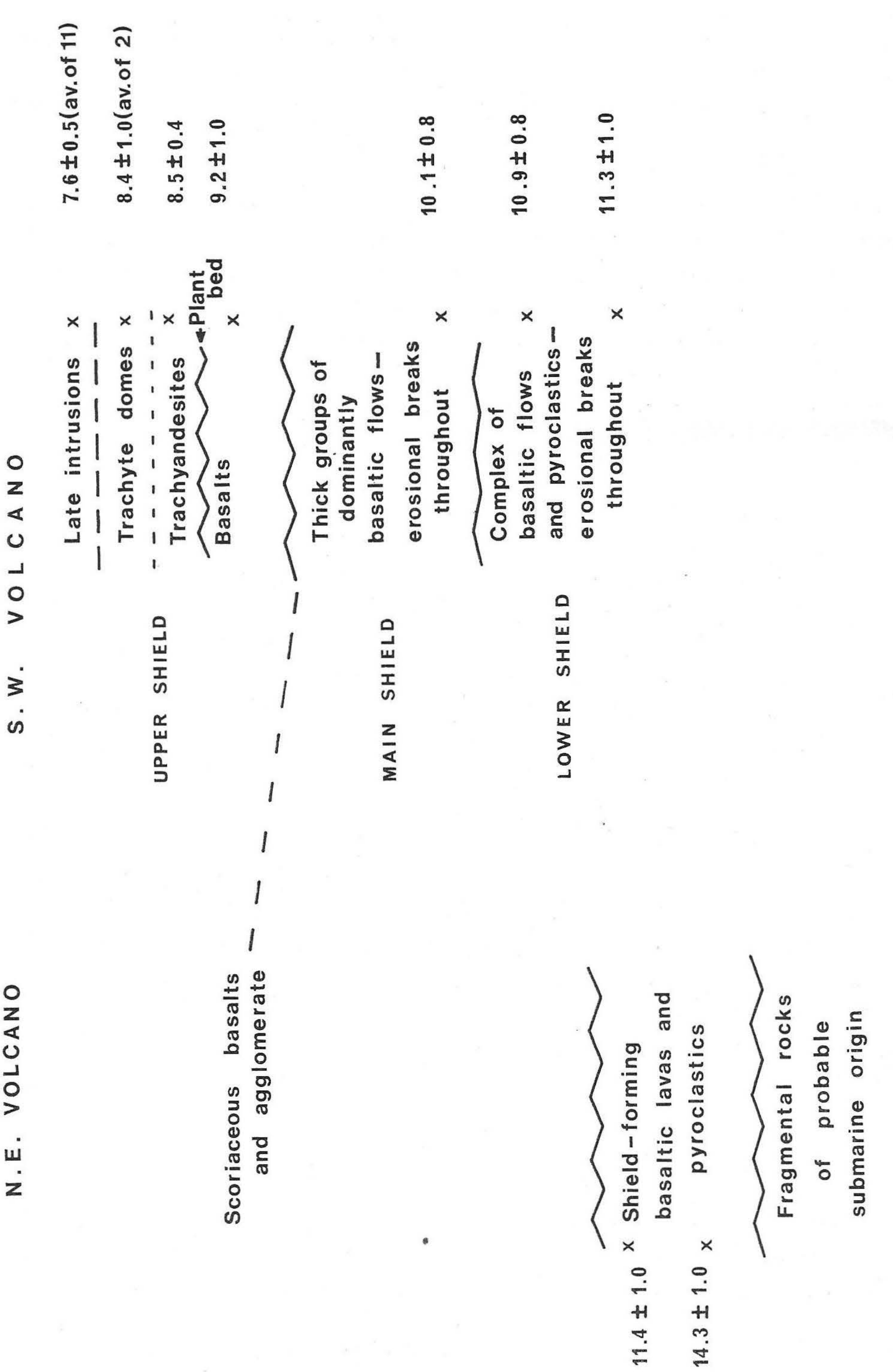

Fig. 5. — Stratigraphic divisions, relative and absolute age relations of rocks of the two volcanoes. x = stratigraphic position of dated rocks. Irregular lines denote major unconformities. Dashed lines for SW volcano denote possible erosional breaks.

Lower Shield.

The oldest division of the volcano (11.3 ± 1.0 million to 10.1 ± 0.8 million years ago) is the most complex. Individual groups of basaltic flows are separated by deposits of extensive scoria cone activity. Typically the activity consisted of a quietly effusive period from a « centre » in the region surrounding Lot's Wife, followed by the development of a number of scoria cones over part or the whole of the earlier basaltic « shield » (Plate I). Erosion modified the topography moderately or greatly before another relatively quiet period of activity poured out lavas which tended to bury the cones and generally smooth out the form of the volcano. The Lower Shield at its maximum development attained an elevation of from 500 m to 600 m above sea-level.

A moderately well-defined erosion surface separates rocks of the Lower and Main Shields, but its exposed relief is only measurable in terms of several tens of meters.

Main Shield.

The dominant lava flows of this stage (10.1 ± 0.8 million to approximately 9.6 ± 0.8 million years ago) were erupted from fissure systems in Sandy Bay and to a very minor extent in Manati Bay. Not less than 800 m of flows were extruded in little more than half a million years, and several marked erosional unconformities occur in the sequence (Plate II). Typically periods of activity commenced with an explosive ash phase and were followed, although not necessarily immediately, by the extrusion of lava flows — erosion surfaces are almost invariably cut into the lava flows and not the ash horizons. Pyroclastic activity from the central regions became subordinate to parasitic scoria activity, which extended intermittently throughout the growth of the volcano. Consequently a number of often large cinder cones were built up on the flanks of the volcano, which by this stage was broadly shield-like in profile. Whereas during the Lower Shield stage the volcano surface would have been frequently and extensively covered with ash, during the Main Shield stage only local areas were affected, and broad areas of the flanks would have been left clear. The Main Shield probably attained an elevation of little more than 1,200 m above sea-level in a position equivalent to the central Sandy Bay area.

Upper Shield.

The major erosional unconformity separating the Main and Upper Shields (Fig. 5) could conceivably represent a period of quiescence of up to half a million years. Extensive portions of the flanks of both volcanoes were very deeply eroded in the north-east and east of the island where a relief on the unconformity of more than 400 m is exposed. Dated rocks of the Upper Shield range in age between

9.2 ± 1.0 million and 8.4 ± 1.0 million years old (Fig. 5) — one flow possibly belonging to this stage was dated as 9.6 ± 0.8 million years old. Activity was almost exclusively effusive and an early group of thick basalts was followed by a sequence of more extensive thicker trachyandesites — thin ash horizons rarely separate lava flows (Plate III). Extrusive activity, although producing flows of very wide extent, was markedly intermittent; another pronounced unconformity separates the two groups of lavas, and the trachyandesite flows are usually separated by erosional surfaces. Finally two massive trachytic flow domes (The Stone Tops) and a petrographically unique trachyandesite flow (Bencoolen) were extruded over a small area in the east of the island (map 2).

Lavas of the Upper Shield were extruded from a zone approximately coincident with the area of the central Peaks (map 2), i.e. originally high on the flanks of the volcano of the Main Shield stage. The Upper Shield lavas therefore added nothing to the maximum elevation of the island — in fact the attitudes of these flows indicate that the central regions of the Main Shield were already quite deeply eroded prior to their extrusion.

Effusive activity appears to have ceased at this time (8.4 ± 1.0 million years ago).

Late intrusive rocks.

The final stage of volcanic activity was marked by the intrusion of a group of trachytic and phonolitic rocks into the south-western volcano (Baker, 1968b). A number of individual intrusions, three major dykes (preserved in such monoliths as Lot, Lot's Wife and the Asses Ears - Plates I and IV), and a number of minor dykes were emplaced at extremely high level into the volcano (map 2) approximately seven and a hafl million years ago (7.6 ± 0.5 million years is the average of eleven dates ranging from 6.8 ± 0.4 million to 8.4 ± 0.6 million years ago). It is possible that in one locality, near White Hill on the eastern rim of Sandy Bay, the dykes broke surface and extruded flows over little more than one square kilometer of the flanks; elsewhere there is no evidence that the intrusions broke surface.

Subsequent and contemporaneous fumarolic activity almost certainly affected considerable areas of the volcanoes, notably in the south-west, central and western areas of the south-western volcano. Extensive alteration of the rocks in the Flagstaff Hill - Longwood, and Stone Tops - Levelwood areas may also be of hydrothermal origin in part. However, much of this and other alteration may be younger than all volcanic activity, merely reflecting deep weathering conditions under subtropical conditions.

This brief account of the geological history has a direct bearing on the establishment of the island's flora and fauna. Not only do the potassium-argon absolute age determinations give a maximum age of the island for the initiation of colonization, but the volcanic history may indicate periods of favourable or unfavourable conditions for the earliest life-forms to arrive and develop. Although it cannot be proved, even by the absolute age determinations, it seems likely that activity in the north-east ceased, or at least was very greatly reduced, at about the time that the Lower Shield activity commenced in the south-west. The widespread and frequent activity in the early life of the south-western volcano would have made colonization extremely hazardous, certainly up to the Main Shield stage. However, the north-eastern volcano probably afforded a relatively undisturbed area for the early *extensive* development of floral and faunal colonies, some eleven million years ago. Lavas of the Main Shield stage of the south-western volcano lapped onto the north-eastern shield (map 2), eventually burying the flanks through some 180° of arc (NW through SW to SE) to a height of up to 600 m. This activity would have restricted any flora and fauna developed in the north-east to the topmost few hundred meters of the volcano (the areas today equivalent to Sugarloaf and Flagstaff Hills and The Barn) (map 2) immediately prior to the major period of quiescence approximately 9.5 million years ago. This first major period of quiescence in the history of the south-western volcano marked the earliest time at which wide-spread colonization of the entire island could have taken place. Subsequent activity of the Upper Shield, while voluminous, was restricted areally probably to little more than half of the island. The youngest rocks of the north-eastern volcano which are of approximately coincident age (Fig. 5) are restricted to a small area in Rupert's Valley. From the distribution of flows of the Upper Shield it is possible to envisage the latest lavas lapping round the early bastion of the north-east and separating numerous small topographic highs from each other over most of the remainder of the island. The flora and fauna of the island would have undergone another, and final, period of restriction, and it is interesting to point out that in many instances these Upper Shield lavas were channelled down existing valleys and their major influence would have been to destroy much of the flora and fauna that is restricted to this ecological environment.

PLIOCENE FLORAL ASSEMBLAGE

As was remarked earlier, no soil horizons are known to be interbedded with the lavas of either volcano. However, in the east of the island at the inland end of Turk's Cap Ridge (map 2) a sequence of fluviatile and detrital sediments containing a spore-pollen assemblage representing a varied flora are preserved, underlying a trachyandesite flow of the Upper Shield (dated as 8.5 $\pm$ 0.4 million years old). The flora has been described elsewhere (Muir and Baker, 1968), but a few general considerations are pertinent to the faunal colonization of the island.

The assemblage is greatly dominated (75 % of recognizable species) by bilateral polypodiacean spores; only one other species makes up more than 5 % of the assemblage (*Lygodium* sp., 6.8 %). The remainder of the assemblage consists of *Vittaria* sp. (4.5 %), *Grammitia* (1.9 %), *Eohitricolporites spinosus* (2.1 %), *Lycapodites* sp. (1.9 %), *Pteris* sp. (0.8 %), two species of Lycopods (together 0.6 %), and several other species (totalling 6.4 %) all of which constitute individually less than 1 % of the total assemblage. The Pliocene assemblage therefore contrasts strongly with the present indigenous flora (MELLISS, 1875; HEMSLEY, 1885) — the former is dominated by ferns, the latter by angiosperms. It has been noted, for example on Krakatoa (GUPPY, 1906), that the earliest floral assemblage to establish itself on a volcanic island may be rich in ferns, and the Pliocene assemblage on Saint Helena has been interpreted as an early colonizing flora (MUIR and BAKER, 1968).

Two occurrences of tree trunk casts in lavas of the island were recorded by MELLISS (1875); these lavas are younger than 10.1 ± 1.0 million years and older than 9.3 ± 0.6 million years (BAKER *et al.*, 1967). Traces of flora earlier than this Pliocene spore and pollen assemblage are therefore extremely rare, and it would appear that the flora developed in the period of quiescence between the Main and Upper Shield stages of the south-western volcano marks the earliest development of an extensive vegetation cover. It seems quite possible that this same erosional interval, approximately nine and a half million years ago, was the second probable chance that a colonizing diverse fauna had of definitely establishing itself throughout the island.

OBSERVATIONS ON THE PALAEOCLIMATE

Cinder cones that were built up periodically throughout the growth of both volcanoes are asymmetrical, with their finer ash carried farther to the north-west. In Upper Miocene and Lower Pliocene times therefore the South-East Trades were already established as the dominant winds in this area of the South Atlantic. This is also important in relation to the probable development of faunal and floral colonies on the north-eastern volcano once activity had commenced in the south-west. Ash and acid gas clouds accompanying volcanic activity would therefore have been carried to the north-west, and consequently would have had negligible affect on any early colonization in the north-east.

At several localities along the south coast of the island, and between Flagstaff and Sugarloaf Hills in the north-north-east, deposits of wind-blown calcareous sand are dune-bedded in directions coincident with wind directions existing at the present time. The deposits are of coarse beach sands consisting of comminuted fragments of an abundant marine, essentially littoral, fauna including echinoids, lamellibranchs, gastropods, foraminifera, polyzoans, scleractinian corals and ophiuroids. The fauna is representative of warm water, probably slightly warmer than that at present surrounding the island. No shell beaches exist at the present time. The deposits are earlier (BAKER, 1968a) than the five-meter raised beach which surrounds most of the island and probably represents a final eustatic lowering of sea-level. The sands were formed at sea-level, either before the onset of the Plio-Pleistocene glaciations or during a warm interglacial period. The transport of these coarse sands to elevations of up to 400 m would necessitate much stronger winds than exist at present, and it seems likely that during the Pleistocene wind velocities were periodically greatly increased as a result of the northerly shift of the Antarctic ice-cap (MUIR and BAKER, *op. cit.*) A shift of the Antarctic Convergence of more than 5° of latitude to the north during a glacial maximum between 2.35 and 3.35 million years ago has been indicated from a study of marine cores in the Southern Ocean (GOODELL, WATKINS, MATHER and KOSTER, 1968).

MUIR and BAKER (*op. cit.*) have suggested that these increased wind velocities were responsible in part for the erosion of the fern dominated Pliocene flora, and the winds became more powerful tools for the transportation of angiosperms from southern Africa — types which now dominate the island's indigenous flora. The effect of these increased South-East Trades must have been considerable on certain faunal species, both those dependent upon wind for transportation and/or those not suited to conditions of very high wind velocities.

CONCLUSIONS

Sub-aerial volcanism initiated the island of Saint Helena not less than 14.3 ± 1.0 million years ago, and volcanic activity of variable intensity continued until approximately seven million years ago.

Activity in the older (the north-eastern) of the island's two volcanoes essentially ended 11.4 ± 1.0 million years ago, and this volcano provided a relatively stable land area for potential early floral and faunal colonization.

Continued activity in the south-west built up a much larger volcano, some products from which would have caused a reduction in land area available for plant and animal life about 9.5 million years ago when they flooded substantial areas of the earlier mass.

Prolonged quiescence of perhaps half a million years at this stage made available the entire area of the island, probably approximately equivalent to the present land area, for extensive faunal and floral colonization and development.

Volcanic activity after this major period of quiescence was sporadic but affected considerable areas of the island, mainly in the high central ground, the east and the north-east. The topographic highs corresponding to the original central regions of the north-eastern volcano were unaffected, but many drainage valleys of the south-western volcano were flooded by lavas.

Virtually no extrusive activity occurred after 8.4 $\pm$ 1.0 million years ago, and the final intrusive volcanism ended approximately a million years later.

SCHWARTZBACH (1963) has suggested that the main oceanic current patterns for the South Atlantic were established in the Tertiary, and evidence presented here indicates the existence of dominant South-East Trade winds throughout the life of Saint Helena. The transportation mechanisms for colonizing plants and animals were therefore closely comparable to those existing at the present time.

Evidence from the island indicates a marked increase in wind velocities at some stage, or stages, during glacial times. The probable importance of these increased winds has been discussed in relation to changes in the island's flora (MUIR and BAKER, 1968), but their possible affects on the fauna remain to be seen.

The complex patterns of volcanism and quiescence during the growth and development of the island have been discussed above; it is hoped that they will provide a useful part in the interpretation of the origins of the unusual indigenous creatures of Saint Helena.

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REFERENCES

BAKER, I. — The geology of Saint Helena Island, South Atlantic. Unpublished Ph. D. Thesis, University of London (1968a).

BAKER, I. — Compositional variation of minor intrusions and the form of a volcano magma chamber. *Quart. J. Geol. Soc.*, 124, 67-79 (1968b).

BAKER, I. — Petrology of the volcanic rocks of Saint Helena Island, South Atlantic. *Bull. Geol. Soc. Am.*, 80 (7), 1283-1310 (1969).

BAKER, I., N.H. GALE and J. SIMONS. — Geochronology of the Saint Helena volcanoes. *Nature*, 215, 1451-6 (1967).

GOODELL, H.G., N.D. WATKINS, TT. MATHER and S. KOSTER. — The Antarctic glacial history recorded in sediments of the Southern Ocean. *Palaeogeog. Palaeoclimat. Palaeoecol.*, 5, 41-62 (1968).

GUPPY, H.B. — Observations of a naturalist in the Pacific. Plant dispersal. Macmillans, London (1906).

HEMSLEY. W.B. — Reports on the scientific results of the voyage of the H.M.S. Challenger. Botany, vol. 1 (1885).

MELLISS J.C. — Saint Helena; a physical, historical and topographical description of the island, including the geology, fauna, flora, and meteorology. London (1875).

MUIR, M.D. and I. BAKER. — The Early Pliocene flora of Saint Helena. *Palaeogeography, Palaeoclimatol. Palaeoecol.*, 5, 251-268 (1968).

SCHWARTZBACH, H.M. — Climates of the past. London, Princetown, New York and Toronto (1963).

Map 2. — Major stratigraphic divisions of the Saint Helena volcanoes. (Inset is position of the 50-fathom line.) Older north-eastern volcano lies inside ticked line; south-western volcano : Lower Shield is in south and south-west; M = rocks of the Main Shield stage; U = rocks of the Upper Shield stage — note especially their development along original radial drainage pattern; dotted areas = trachytic and associated extrusive rocks of Upper Shield; black = late intrusive rocks.

PLATE XX

1. — Deeply dissected central region of the south-western volcano. Country rocks (except the thick flow on skyline) are flows and scoria of the Lower Shield. Some basaltic feeder dykes are apparent, and late phonolitic dykes are seen in the Asses Ears (skyline, left) and Lot's Wife (extreme right).

2. — North coast of the island (Jamestown lies in valley behind the group of buildings). Basaltic flows and thin scoria horizons of the Main Shield of the south-western volcano rest on shield-forming rocks of the north-eastern volcano, unconformity is poorly exposed running from middle of valley side (left) to below buildings (right).

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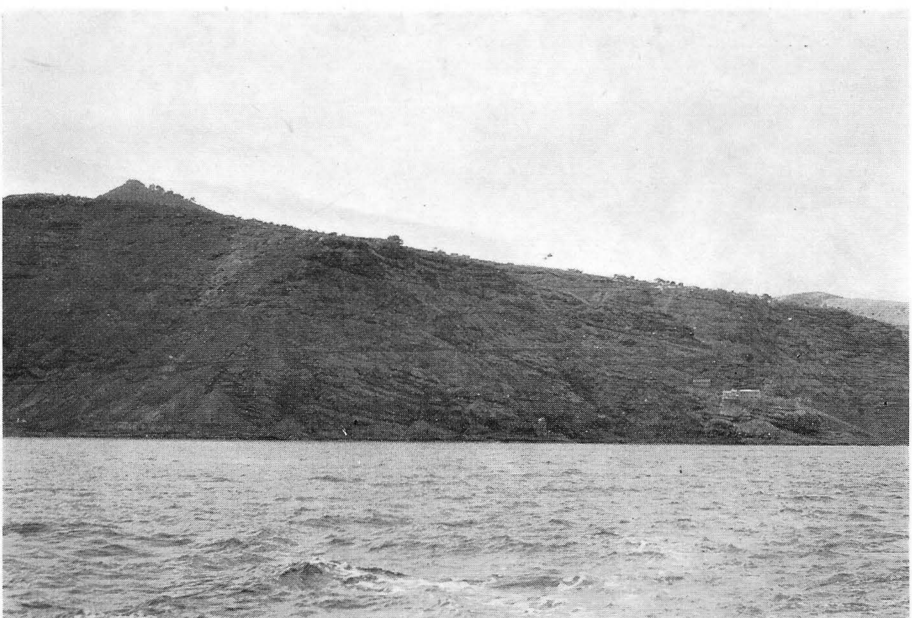

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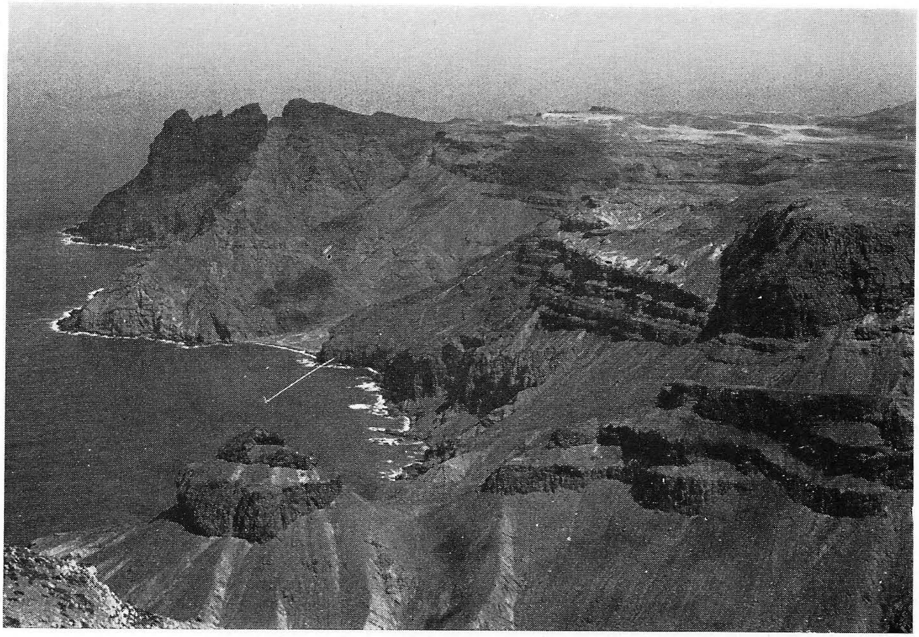
PLATE XXI

1. — East coast from Turk's Cap (foreground) to King and Queen Rocks. Prominent nearly horizontal lavas (centre) are flows of the Upper Shield of the south-western volcano; they unconformably overlie rocks of the Main Shield stage (distance), and submarine breccias of the north-eastern volcano in the foreground. Plant bed (see text) underlies the flows of Turk's Cap Ridge, a little to the right of the photograph.

2. — Late intrusive dyke-controlled plug of Lot in Sandy Bay (south-western volcano). Gullying is developed in rocks of the Lower Shield; NE - SW dykes are very apparent on left. Skyline right shows start of the central Peaks.



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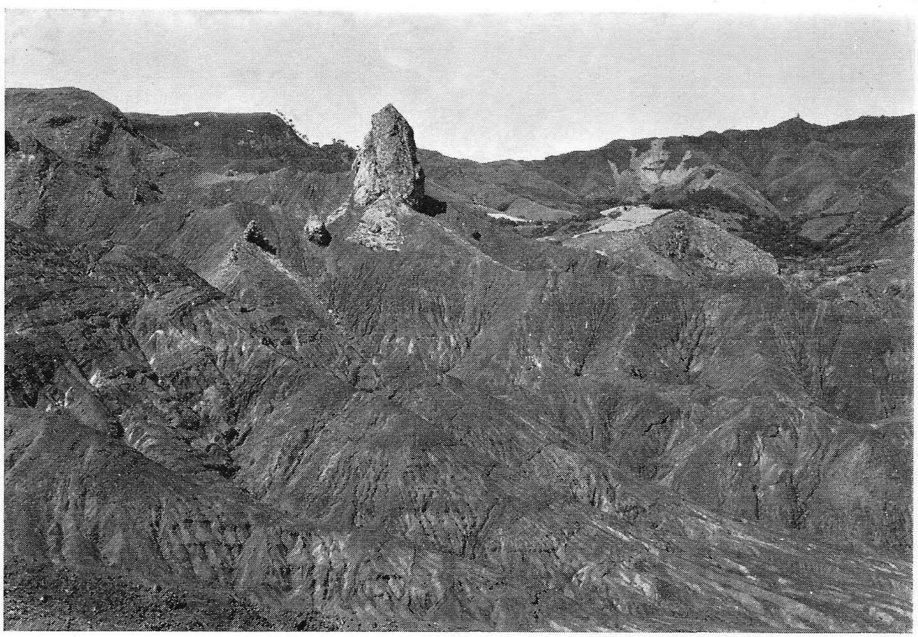

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