The 1961 Eruption; photograph taken from the helicopter of H.M.S. *Protector* on 20 March 1962. Crown Copyright.

THE VOLCANOLOGICAL REPORT OF THE ROYAL SOCIETY EXPEDITION TO TRISTAN DA CUNHA, 1962

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[Frontispiece, Plates 16 to 33 and coloured map]

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PART I. GENERAL INTRODUCTION

1. The Expedition

On the night of 9 October 1961, following a period of severe but localized earth tremors, a volcano erupted on the Settlement Plain of Tristan da Cunha only 300 yards to the east of the village. The island was evacuated the following day. In November of that year the Royal Society approved a proposal to send an expedition to the island to study the new volcano, to make a geological survey of the Tristan group and to investigate the effect of the volcanic activity on the vegetation and fauna of the island. A Tristan da Cunha Committee, with Professor L. R. Wager, F.R.S., as chairman, was set up. Professor W. Q. Kennedy, F.R.S., was appointed Senior Scientific Director and Professor C. F. A. Pantin, F.R.S., Biological Director to the Expedition. The Trustees of the World Wild Life Fund supported the project enthusiastically and made it possible for a botanist and zoologist to be included in the party.

On 6 December 1961, Dr P. G. Harris and Dr R. W. Le Maitre left the United Kingdom for Tristan travelling from Freetown, Sierra Leone, aboard H.M.S. *Jaguar*. The object of the visit was to examine the state of the volcanic activity at that time and to make any reconnaissance that might be of assistance to the main Expedition scheduled to arrive on the island during January 1962 (Harris & Le Maitre 1962).

The main Expedition consisted of twelve members: Dr I. G. Gass (leader), Dr P. G. Harris, Dr R. W. Le Maitre and Mr P. E. Baker (geologists); Mr J. H. Dickson (botanist); Mr D. E. Baird (zoologist); Lt.-Com. A. B. Crawford, S.A.N.R. (meteorologist and deputy leader); Mr D. Simpson (agriculturalist); Staff-Sgt. R. Shaw and Cpl. T. McCormack (Royal Corps of Signals); and Mr Joseph Glass and Mr Adam Swain (Tristan Islanders; guides).

The Expedition sailed from Simonstown, South Africa, on 22 January 1962, aboard the South African Navy frigate S.A.S. *Transvaal*, and after two days delay due to bad weather landed on Tristan on 29 January. The party was relieved by the Royal Navy ice patrol vessel H.M.S. *Protector* on 20 March 1962. The account presented herein is based on 7 weeks' field work in the area, 6 weeks being spent on Tristan da Cunha and 1 week on the nearby islands of Inaccessible and Nightingale. A detailed study was made of the new parasitic volcano and a record kept of its activity during the Expedition's period of residence. A geological survey of Tristan da Cunha was made, and geological investigations were undertaken on Inaccessible and Nightingale Islands. The effects of the volcanic activity on the vegetation, and the direct and indirect effect on the introduced and indigenous fauna were examined.

The headquarters of the Expedition was established at the Settlement in the Administrator's residence and work on the north side of the island was conducted from here. Temporary camps were established at Sandy Point and Stony Beach, and investigation of the Base was made from camps at Burntwood and Gipsy's Gulch.

2. Location, form and environment of the Tristan da Cunha Group

The Tristan da Cunha group of islands takes its name from the largest of a group of three islands that lie in the South Atlantic (37° 05′ S, 12° 17′ W) almost mid-way between South Africa and the east coast of South America. The position of the group is depicted on figure 1. Gough Island, which lies some 230 miles SSE of the other three islands, is included with them for administrative purposes and is closely similar in its geology, climate and biology. In this report only the three islands of Tristan da Cunha, Nightingale and Inaccessible, together with their numerous offshore rocks and islets, are discussed in detail. In accordance with local usage the main island of the group is hereafter referred to simply as 'Tristan'.

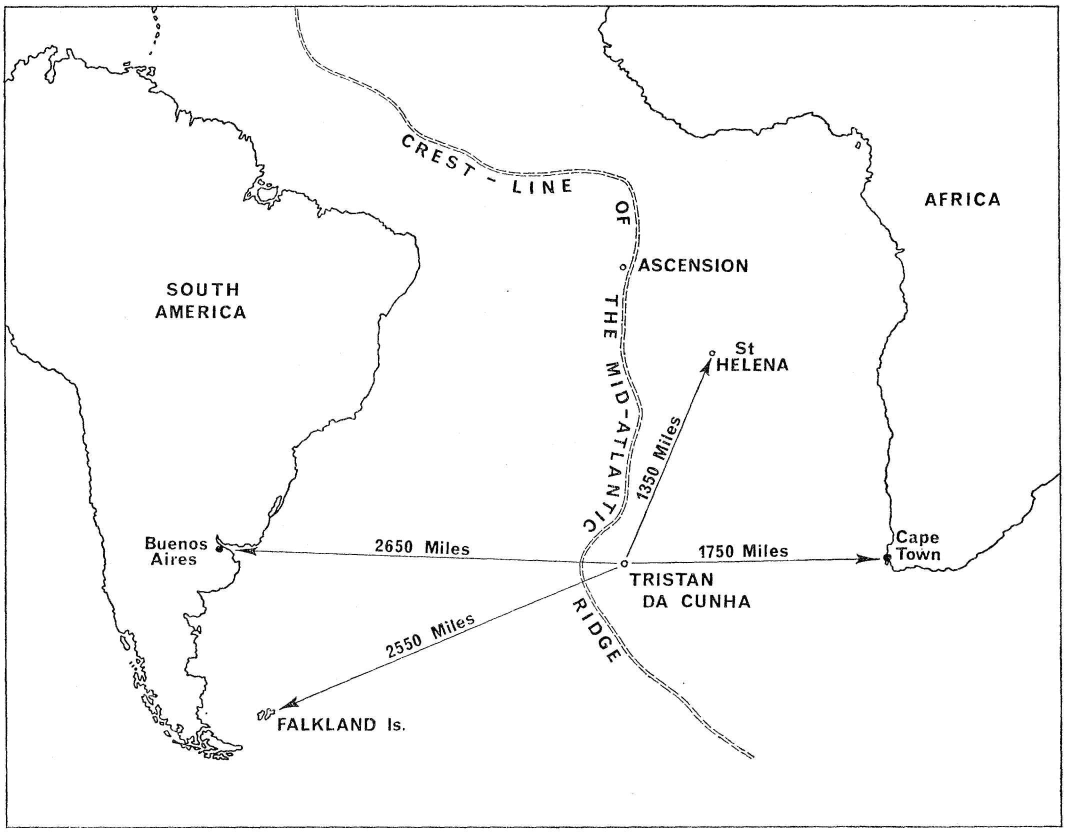

FIGURE 1. Tristan da Cunha: location diagram.

Tristan has long been considered to be one of the isolated volcanic islands that lie on or along the flanks of the Mid-Atlantic Ridge. In fact, the crest of the Mid-Atlantic Ridge lies some 300 miles to the west of the Tristan da Cunha Group and these islands are the uppermost parts of huge volcanic cones that rise abruptly from the relatively gentle outer slopes of the ridge some 12000 ft. below sea-level. Even so, the Tristan da Cunha Group lies within a large arc of the Mid-Atlantic Ridge, which is concave to the east, and most probably the volcanic activity is associated with this major earth structure.

Bathymetric surveys undertaken by H.M.S. *Owen* in 1961, and H.M.S. *Protector* in 1962, clearly show that the island of Tristan is the uppermost 6760 ft. of a huge, symmetrical volcanic cone. Figure 2, a bathymetric chart of the Tristan da Cunha Group contoured at 100-fathom intervals, shows the near-perfect conical form of Tristan.

The bathymetric contours around the smaller islands of Inaccessible and Nightingale are more irregular and the presence of an extensive shallow-water platform, that surrounds and lies between the islands, suggests that they are eroded remnants of once larger volcanic islands. Between Tristan and the two smaller islands, the water reaches a depth of 8000 ft.

Later in this report the physiography of the three islands will be described in detail. It is, however, thought desirable that their form should be briefly mentioned here. Tristan is roughly circular in plan with an average diameter of between 7 and 8 miles and consists of a central conical peak (6760 ft. O.D.) from which the land falls away with diminishing gradient to about 2000 ft. Below this are almost vertical cliffs, often to the sea. Local terms for the major topographic features are: *The Peak*, for the steeply inclined, central area above 3000 ft.; *The Base*, for the gently inclined vegetated area between 2000 and 3000 ft.; *The Main Cliffs*, for the 2000 ft. cliffs that bound the island; and *The Coastal Strips*,

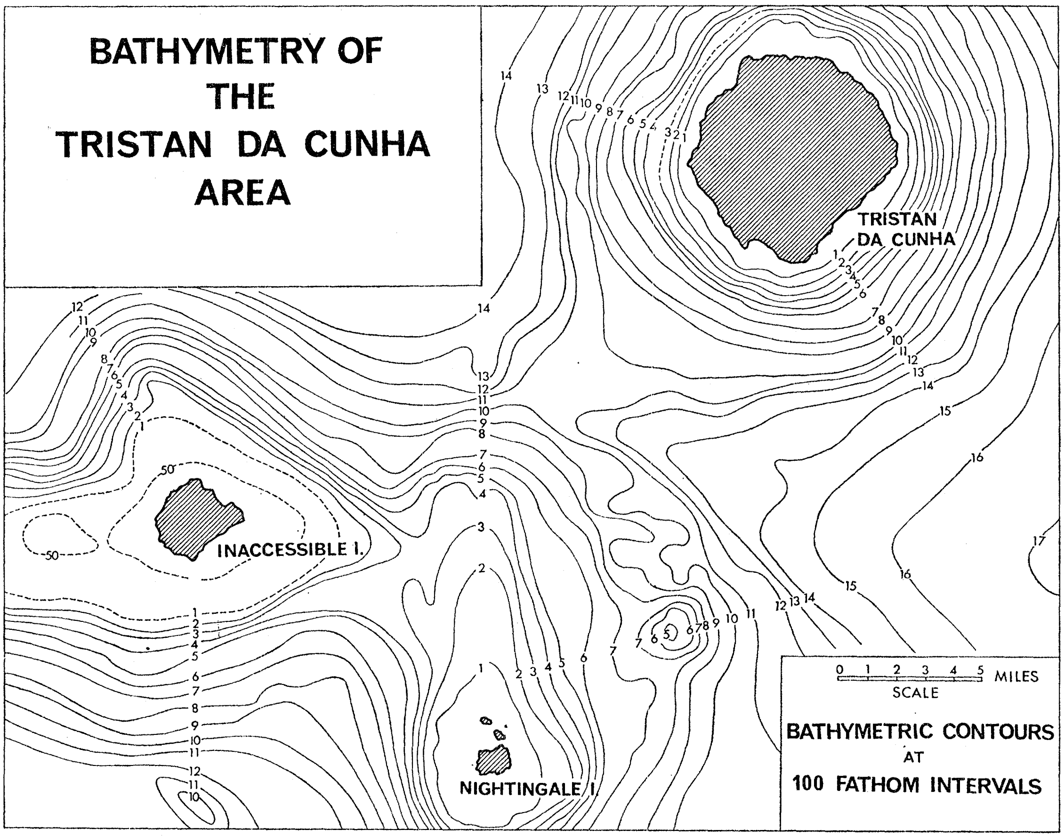

FIGURE 2

for the low-lying areas between the Main Cliffs and the sea. Under the general term of Nightingale Island are the three relatively large islands of Nightingale (planar area 1 sq. mile), Middle and Stoltenhoff, together with numerous off-shore rocks and islets. All are low-lying, the highest point barely exceeding 1200 ft., and are covered for the main part by dense tussock grassland. Inaccessible Island is rhomboidal in shape with a planar area of about 4 sq. miles and consists of a relatively flat surface varying in height from 900 ft. in the east to 1800 ft. in the west surrounded by near-vertical cliffs. A few islets lie close in-shore.

Climate. The Tristan da Cunha Group lies within the belt of westerly winds which have earned the name 'roaring forties' for the latitudes just to the south. The strongest winds are experienced in the winter months, the actual direction fluctuating between north-west and south-west. The weather associated with south-westerly winds is usually cold with squalls and sunny periods, whereas the north-westerly winds bring relatively warm but overcast weather. However, in spite of the frequency of winter gales and storms the climate is basically temperate. From March to December it is largely influenced by depressions which migrate from west to east at speeds of 15 to 20 knots. The frontal systems associated with these depressions bring high rainfall, which is considerably augmented by local orographic precipitation. During the summer months, December to February, the South Atlantic anti-cyclone belt moves southwards resulting in improved weather, especially when the wind is south-easterly.

Rainfall, cloud amount and sunshine records are all affected by local orographic factors. The annual rainfall, 65 in. at the Settlement and about 200 in. on the Peak, falls especially during the winter months (April to December) but the summers are still rather wet. During the winter and spring the Base and Peak are snow covered, but snow is never seen at the Settlement where the temperature seldom falls below 40 °F. The mean air temperature for February (the warmest month) is about 65 °F (18 °C) and for August (the coldest month) it is 52 °F (11 °C). Relative humidity is high, the average figure being about 80 %. Cloud amount is generally considerable; during the north-westerly wind situation semi-permanent orographic cloud covers seven-eighths of the sky.

Ocean currents. The surface ocean currents in the Tristan da Cunha area are largely influenced by the wind circulation over the South Atlantic as a whole. The island is situated on the south side of the South Atlantic anti-cyclonic belt and in sympathy with the prevailing 'westerlies' the currents have an easterly set. There are three further influencing factors; the north-easterly set of cold water coming up from the Weddell Sea, the movement of the water through the Drake Passage between Cape Horn and Graham Land, and the strong northerly current on the east side of the anti-cyclone caused by the strong trade winds in the area just west of the Cape of Good Hope. The net result of all these influences is an east-north-easterly set in the Tristan area. This is maintained throughout the year. The information on which these currents can be based is relatively sparse, for the area lies well south of the normal shipping routes. However, examination of British, American and Dutch current charts gives figures which can be resolved into table 1. The values tabulated are probably maximal rather than mean rates, for Deacon (1960) states that the average daily rate of flow of the southern circumpolar west wind drift is about 8 miles per day, and Defant (1961) suggests general sets of about 12 miles per day.

TABLE 1

season	month	direction to	miles per day
summer	December	ENE	17
	January	ENE	17
	February	ENE	18
autumn	March	ENE	20
	April	NE	22
	May	NE	22
winter	June	NE	22
	July	NE	22
	August	NE	22
spring	September	NE	20
	October	NE	20
	November	ENE	17

Observations confirm the strong easterly set, for instance a ship anchored off the Settlement will usually lie to the eastward of her anchor.

The mean position of the subtropical convergence is generally considered to lie very near to the three northern islands, but this boundary regions shows a considerable north–south movement with season and may at times lie well to the north of Tristan. Sub-Antarctic cold temperate and cold temperate mixed water types (Knox 1960) affect the islands, the mean summer temperature of the sea being about 18 °C at Tristan and 14 °C at Gough, while the winter figures are about 13 °C and 11 °C respectively.

Tides. As far as is known, no systematic tidal measurements have ever been taken at Tristan. The island, being roughly circular, has no bays of any appreciable size and all beaches are 'steep-to'. Tidal movements are therefore hardly noticeable. Casual tidal observations recorded by Lt.-Cdr A. B. Crawford, S.A.N.R., indicate a vertical range of 18 in. during neap tides, and between 3 and 4 ft. during spring tides.

3. Historical synopsis

This synopsis deals very briefly with the main events in the history of the Tristan da Cunha Group; for further details the reader is referred to excellent accounts by Brander (1940) and Munch (1945).

Tristan da Cunha was discovered in 1506 by the Portuguese Admiral, Tristão d'Acunha, after whom it is named, and Gough Island by another Portuguese, Gonçalo Alvarez, at about the same time. Nightingale is named after Captain Gamaliel Nightingale, R.N., who visited the area in 1760.

From 1790 onwards, Tristan was periodically visted by small parties of sealers and whalers, who spent periods of weeks or months ashore killing fur seals and 'trying out' elephant seal blubber for oil. Owing to excessive slaughter, these visits became uneconomic by about 1820, although there was a brief resurgence of sealing in 1880–90 when the stocks had somewhat recovered. Whaling vessels, however, continued to make occasional calls in search of fresh water. The island was sometimes used as a port of call by sailing vessels bound for the Cape of Good Hope, India and Australia; these vessels sailed far into the South Atlantic in order to catch the favourable westerly winds.

It was this situation on a major sea-route that led Jonathan Lambert, with two companions, to establish the first settlement on the island in 1810. Lambert proposed to supply fresh provisions to passing ships, and to exploit the natural resources of the islands. His death at sea in 1812 terminated this scheme, but his surviving companion was soon joined by two whalers and this pioneer colony was in being when a small British garrison landed on the island in August 1816. During the Anglo-American war of 1812–14 American privateers and men-of-war had used Tristan as a base from which to prey on East Indiamen, and the occupation of the island may have been designed to prevent this as much as for the traditional reason of denying the French a base from which to rescue Napoleon from St Helena.

It appears that the British Government soon considered the Tristan garrison to be of little use, for it was withdrawn on 27 September 1817. However, Corporal William Glass, a member of the garrison, his wife and family and two stonemasons obtained permission to remain, and they were soon joined by a number of other colonists.

Between 1817 and 1836 the population of Tristan fluctuated considerably, recruiting men from shipwrecks and the crews of visiting whalers, and obtaining wives from St Helena. Many of the early settlers left the island, and at least twelve of Glass's sixteen children either took service in or married men aboard American whalers. The island continued to maintain intermittent contacts, and exchange personnel, with the outside world until about 1908, although after about 1886 the isolation of the community, largely through a decline in the number of passing sailing ships, increased steadily. A major exodus, of fifty people, occurred in 1857, and in 1885 fifteen men, the majority of the able-bodied male population, were drowned while attempting to intercept a passing vessel. Between 1885 and 1900 about 60 people left the island although a number of these returned in 1908. This returning population provided the last major influx of new blood to the community. After 1908 passing ships became less and less frequent, trade declined, and mounting population coupled with inefficient agriculture progressively reduced the standard of living of the community.

The community never was truly self-sufficient; it was a trading post. Thus, in 1867 a visiting naval captain commented that 'not less than an average of twenty ships annually called at the Settlement for food and water'. Between 1820 and 1850 American whalers maintained very close contact and communication with St Helena. These trading contacts allowed all the goods that the island could not produce to be obtained in exchange for fresh provisions. It was the breakdown in this trade during 1890–1900 that was, in the the long run, fatal to the standard of living of the island population, although their mounting numbers lowered the agricultural productivity and reduced the available surplus for barter.

During the latter half of the nineteenth century and early twentieth century Anglican missionaries stayed on the island for short periods. Since 1923 clergy have been more or less permanently in residence. These Churchmen, as well as looking after the spiritual welfare of the islanders, also provided elementary education. In 1942, during the Second World War, a naval station, H.M.S. *Atlantic Isle*, was established on the island mainly to deprive enemy surface raiders of a watering station. Radio links were established and the commanding officer of the station, a Surgeon Lt.-Commander, provided the first medical services. Islanders received wages for duties undertaken, and goods such as flour, sugar, rice and tea could be bought from the naval canteen.

It was during the Second World War that one of the naval chaplains, the Reverend C. P. Lawrence, suggested the establishment of a crawfishing industry on the island. This scheme, financed by a Cape Town firm and the Colonial Development Corporation, began operations in 1948, when vessels began crawfishing in Tristan waters. In 1950–51 a canning factory was built at Big Beach, 550 yards NE of the village. The islanders were employed both in the fishing vessels and the factory, and wages earned could buy supplies from the company's canteen. In 1950 an administrator was appointed by the British Government and shortly after, he was joined by a doctor, nurse, agricultural officer and teacher. The meteorological and radio stations, installed during the war, continued to operate, staffed by South African personnel.

When the volcano erupted on the night of 9 October 1961 only 300 yards to the east of the Settlement, the whole population of 264 islanders and 11 officials, their wives and families, was evacuated.

PART II. THE GEOLOGY OF THE TRISTAN DA CUNHA GROUP

1. Introduction

1·1. *Summary of geology*

Tristan is the uppermost 6760 ft. of a composite volcanic cone rising from 12000 ft. below sea-level. For the most part, the island consists of interbedded layers of basaltic lava and pyroclastic material of similar composition derived largely from the central conduit. In common with most composite volcanoes, the inclination of the flows diminishes away from the central vent. This is considered to be mainly due to the increased proportion of pyroclastic material present near the central vent. Buried within this radially inclined sequence are parasitic centres formed mainly by explosive activity at various stages during the evolution of the primary volcano.

Dykes are numerous and usually radiate from the centre of the island; also exposed are volcanic necks or conduits and occasional irregular sills. Superimposed on the flanks of the central volcano are more than thirty secondary cones, principally of pyroclastic origin but often with thin flows interbedded with the scoria and cinder. Most of these cones have summit craters often breached on the seaward side. Usually, where the crater is breached, a hummocky lava field can be identified extending from it. There are only two secondary centres of entirely effusive origin; these are Stony Hill and the 1961 eruptive centre. Stony Hill was active probably between 200 and 300 years ago and was the immediate predecessor of the new parasitic volcano.

Nightingale and Inaccessible are eroded remnants of once much larger volcanic islands. Nightingale and the immediately adjacent islands consist of large monolithic masses of porphyritic trachyte, apparently intruded into a volcanic agglomerate. Inaccessible is similar to Tristan in its geology. It consists of near-horizontal layers of basaltic lava and pyroclastic material. However, stock-like masses are more common and the proportion of dykes present is much greater.

1·2. *Previous work*

Since Tristan was first inhabited, numerous articles, mainly non-technical, have been written by visitors to the island. Nearly all recognize the volcanic form of the island and many include graphic accounts of the topography and vegetation of the main islands. Early published geological information is mainly in the form of petrographic descriptions of isolated specimens collected by expeditions that stayed in the vicinity for a few days: H.M.S. *Challenger* Expedition 1885 (Renard 1889), H.M.S. *Odin* 1904 (Schwarz 1905) M.V. *Quest* 1921–22 (Douglas 1930; Campbell Smith 1930).

The first systematical geological study of the group was undertaken by Dunne (1941), the only geologist of the Norwegian Scientific Expedition to Tristan da Cunha, which stayed on the island for 6 months during the summer of 1937–38. Probably due to the absence of an accurate base map, Dunne's account of the geology of Tristan is mainly concerned with the petrography of specimens collected and little attempt was apparently made to construct a geological map of the island. Dunne also spent considerable time on both Nightingale and Inaccessible.

Since the Second World War vessels on charter to the Falkland Islands Dependencies Survey (now British Antarctic Survey) have called at Tristan and specimens were collected by geologists of this Survey. In 1955, the Gough Island Scientific Survey stayed on Tristan for 6 weeks before they completed their journey to Gough Island; unpublished data collected by this Expedition have generously been made available.

1·3. *Methods of investigation*

1·3·1. *Field methods*

It was realized from the outset that the Expedition's stay on the island would be limited and that its work would have to be of a reconnaissance nature; only chosen areas could be examined in detail. The steepness of the Main Cliffs, the dense vegetation on the Base and prevailing weather conditions, in particular the low cloud base, were serious obstacles to work above the Coastal Strips.

Undoubtedly, some of the best exposures are those in the Main Cliffs. However, these cliffs are not readily accessible and in most cases only the lowermost 100 ft. were examined. At Gipsy's, Hottentot and Plantation Gulches the entire Main Cliff section was examined in relative detail. The dense tree fern vegetation on the Base, although only 3 to 4 ft. high, prevents rapid movement and in many cases the deeply incised gulches necessitate extensive detours. Investigation of this area was therefore mainly confined to the readily accessible stream sections and to the secondary pyroclastic centres.

Three days were spent on Nightingale Island; one party examined the interior of the main island whilst the second group landed on Middle Island and also examined coastal exposures on Nightingale. Two days were spent in the vicinity of Inaccessible Island, but owing to the high seas running at the time a landing could only be made on one day at Salt Bay on the north side of the island. The opportunity was taken, however, to examine all coastal exposures from a motor boat lying off-shore.

H.M.S. *Protector*, having embarked the Expedition on the morning of 20 March 1962, was able to stay in the Tristan area for a further 36 hours. During this period soundings were taken which enabled a bathymetric chart (figure 2) to be constructed. Unfortunately, owing to low cloud, observations from *Protector*'s helicopter were of less value than had been hoped. Nevertheless, the opportunity was taken to examine and photograph the new volcano from the air and to examine part of the north-east quadrant of the Base, which had not been investigated in the field. Flights were also taken around both Nightingale and Inaccessible Islands, and a landing was made at Blenden Hall, the western extremity of Inaccessible Island.

The Expedition was fortunate in having enlarged vertical aerial photographs of the island, and a contoured map of Tristan prepared by the Directorate of Overseas Surveys from these photographs. This map, enlarged to a scale of 1:10000, together with aerial photographs on the scale of 1:25000 were used for plotting data in the field. This information was subsequently reduced to a scale of 1:30000 and appears on the geological map that accompanies this report.

1·3·2. *Laboratory methods*

(*a*) *Optical.* Refractive index measurements were made in sodium light by the immersion method, the liquids being checked immediately after use. Unless otherwise stated, the accuracy of the measurements is $\pm 0{\cdot}002$.

Optic axial angles and extinction angles were measured with a Leitz Four-axis Universal Stage. Unless otherwise stated, the accuracy of the measurement is $\pm 1°$ to $2°$.

Time has not permitted any of the minerals to be analyzed chemically. However, where possible, the composition of the mineral phases has been determined optically mainly from curves given by Tröger (1956), and notes on their determination are given below.

Olivine: the β refractive index was used giving a nominal accuracy of $\pm 1\%$ of the fayalite molecule.

Monoclinic pyroxene: although in many cases the β refractive index and $2V$ were measured no attempt was made to use these to determine their composition owing to the unknown quantitative effect of Al_2O_3, Fe_2O_3 and TiO_2 on the optics of naturally occurring pyroxenes. They have, therefore, simply been divided into groups according to colour in thin section and paragenesis, e.g. the very pale grey-green pyroxenes in the basic rocks are called diopsidic augite; the purplish-brown pyroxenes which occur in a wide range of rocks, titaniferous augite; and the grassy-green pyroxenes in the more acid types, aegirine-augite, unless they are markedly pleochroic with a small extinction angle in which case they are called aegirine.

Amphibole: no attempt has been made to determine the composition from the optics owing to the extremely complicated ionic substitutions that can take place in this group (see also Wilkinson 1961, p. 348). The optics are, therefore, only useful as a rough comparison with chemically analyzed material. The strongly pleochroic reddish-brown amphibole which is common in the xenoliths and occurs as resorbed xenocrysts in many of the rocks has been called kaersutitic hornblende by Dunne (1941, p. 48). However, owing to insufficient data the present authors have decided to call this amphibole by the general term, basaltic hornblende. Dunne (1941, p. 51) called the weakly pleochroic paler brown amphibole occurring as a primary mineral in some of the intermediate rocks, barkevikitic hornblende.

Feldspar: the maximum extinction angle in the zone $\perp$ (010) was used for the plagioclase feldspar, and where possible, the β refractive index was used as well, giving a nominal accuracy of approximately $\pm 2\%$ of the anorthite molecule. No attempt was made to determine the composition of the alkali feldspars from their optics owing to the lack of determinative curves for ternary feldspars essential for volcanic rocks.

Feldspathoids: haüyne was identified from the new lava by X-ray powder photographs. In hand specimen it is bright blue and it is likely that some of the bright blue material identified by Dunne as sodalite (1941, p. 58) is haüyne.

Leucite was identified by X-ray powder photographs and refractive index determinations. This is the first recorded occurrence of this mineral from the Tristan group.

(*b*) *Chemical*. Twenty-nine new rock analyses were completed. Seven were done in the Department of Mineralogy of the British Museum (Natural History) by rapid methods while the remaining twenty-two were done in the Department of Geology, Leeds University. In the Leeds analyses, SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO were determined by the classical method, the other elements being determined by flame photometry, colorimetry, etc.

Trace elements were determined spectrographically by Miss J. M. Rooke, of the Department of Geology, Leeds University, by methods already briefly outlined (Rooke & Fisher 1962).

1·4. *Petrographic nomenclature and summary*

The volcanic rocks of the Tristan da Cunha Group belong to the typical oceanic association of alkali basalt → trachyte. The nomenclature used for these rocks by Dunne (1941) was rather cumbersome and was an elaboration of that used by Campbell Smith (1930). The present authors have adopted a simplified scheme and use the terms alkali basalt, trachybasalt, trachyandesite and trachyte, with suitable prefixes, to cover the normal range of rocks. The validity and use of these terms has been discussed elsewhere (Le Maitre 1962). It should be pointed out, however, that these rocks do contain considerable amounts of normative nepheline (up to nearly 17 % by weight in some cases), but as nepheline is never present as a crystalline phase, with the exception of one phonolitic trachyte, the use of names implying an undersaturated nature, e.g. tephrite, is not thought desirable.

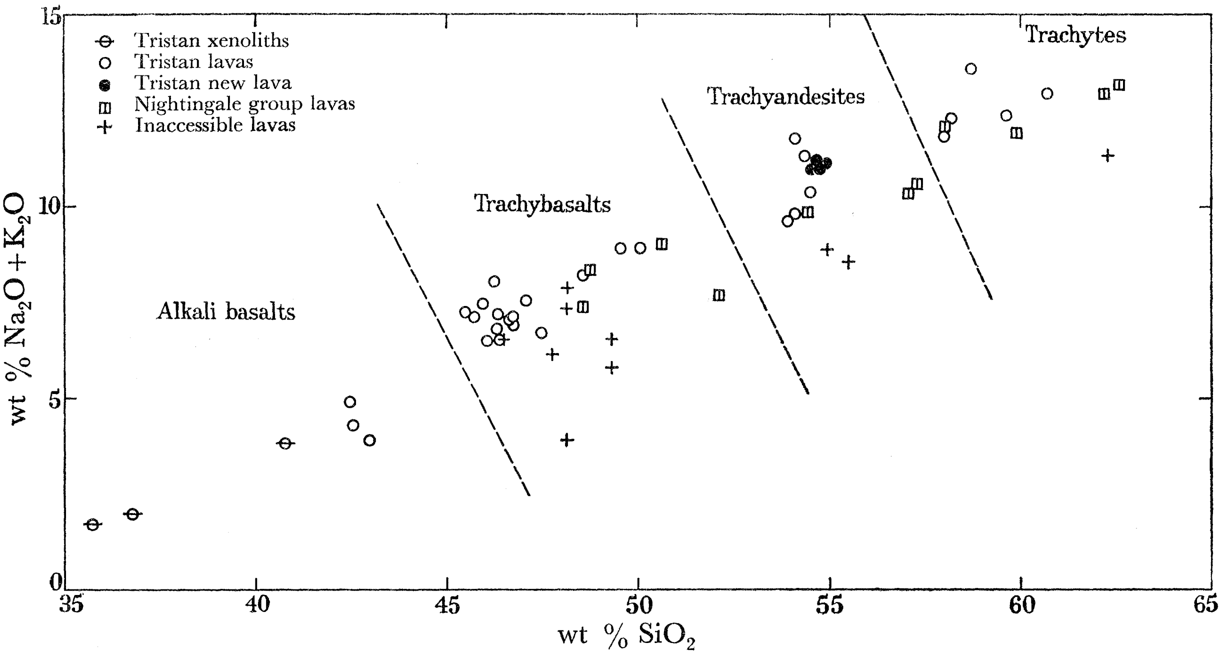

FIGURE 3. Petrographic nomenclature: total alkali/silica diagram.

Owing to the continuous chemical variation of the series and to the well-known difficulties encountered when applying the normal mineralogical classification to volcanic rocks, the divisions between the four major rock types are arbitrary and based on their chemistry. The demarcation lines are shown on the total alkali/silica diagram (figure 3). The trachytes fall naturally into two groups characterized by the phenocrystal feldspar. In one group the phenocrystal feldspar is plagioclase (plagioclase trachytes) and in the other is alkali feldspar (alkali feldspar trachytes). The accumulative rocks have been treated separately and the nomenclature used follows that of Macdonald (1949, p. 1544). The detailed petrography of the analyzed specimens is given in § 2·5.

1·5. *Rock collections*

A total of 686 numbers were allotted to the rock specimens collected by the Expedition during their 7-week visit. The collection was split into three parts. A complete set has been donated to the Department of Mineralogy of the British Museum (Natural History) and is housed under the number B.M. 1962, 128. Individual specimens bear a further number from 1 to 686 corresponding to the number allotted to the specimen by the Expedition; these latter numbers are the ones referred to in this report. The other two sets are incomplete and are housed in the Geology Departments of Leeds and Oxford Universities.

2. The island of Tristan da Cunha

2·1. *Physiography and structure*

2·1·1. *Shape of the Island*

Tristan consists of a central cone 6760 ft. high, containing a small crater lake. On the flanks of the primary volcano are minor parasitic ash and lava cones, none more than 500 to 600 ft. above its surroundings. The outer slopes of the main cone are truncated by a ring of cliffs around the island ranging from 1000 to nearly 3000 ft. above sea-level. Usually the cliffs fall directly to a rocky foreshore, but in places on the north-western, eastern and southern margins of the island, there are narrow fringing strips of land, a hundred or so feet above sea-level, between the foot of the cliffs and the sea. Contrasting with the severe marine erosion, sub-aerial denudation is slight suggesting the youth of the island.

2·1·2. *The Peak and Base*

The upper slopes of the central cone above about 3500 ft. incline steeply outward, with slopes usually from 25° to 30°. Below 3000 ft. to the top of the cliffs, the slopes flatten out to as low as about 8° in some cases. From some viewpoints, the lower, flatter slopes appear to form a pedestal, with the upper part of the central cone super-imposed on top of it. This feature perhaps leads to the local names, the Base for the lower slopes between the cliff tops and about 3000 ft., and the Peak for the higher, steeper slopes up to the summit. This division of the profile above the cliffs is quite marked and distinct on the western and southern slopes especially to an observer standing on the uniformly sloping Base and looking up at the Peak (see figure 23, plate 17). Dunne (1941) considered that this topographic distinction had a structural origin, and that the Base consisted of a pedestal of relatively flat basaltic rocks with a later, steep-sided cone of more viscous lavas superimposed.

On closer study this topographic division is not as sharply defined as it appears at first. In figure 4 are shown vertical profiles through the island, from the central crater to sea-level, and drawn radially at intervals of about 45°. Inspection of these and of the aerial photographs and contour maps confirms observations on the island that the sharp distinction in slope between the Peak and the Base does not occur on the eastern side of the island. Here, although the slopes flatten out downwards, they do so only gradually and to a lesser extent than on the western and southern sides. On the western side, where the slopes appear to change markedly in gradient at the boundary between the Base and the

Peak, this is often exaggerated by the coincidental occurrence of secondary ash cones. In these cases, the change in slope is not between the Base and the Peak but between the Base and a secondary ash slope (figure 4).

The decrease in slope, outwards from the central crater, is a common feature of most large composite volcanoes. It is likely that the major cause is the influence of pyroclastics in determining slope.

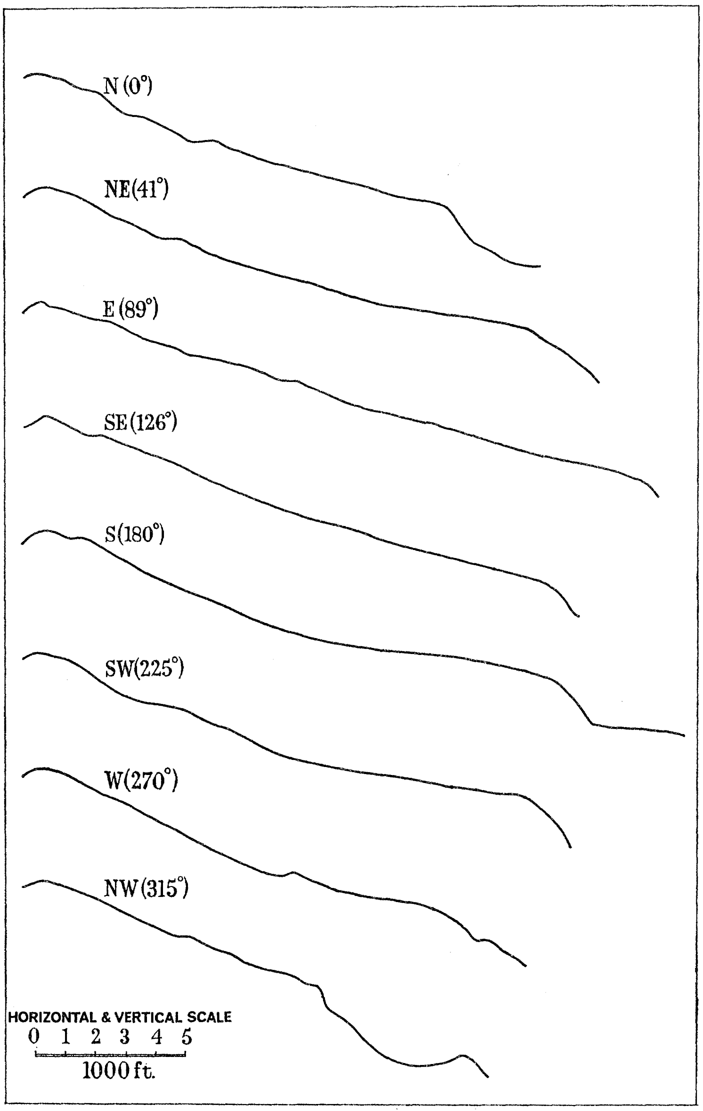

FIGURE 4. Topographic profiles radial from the summit.

On Tristan, in exposures in the Main Cliffs and elsewhere on the Base, ash and scoria make up about 20% of the deposits, the main materials being solid lavas alternating with fragmental horizons which are the blocky or rubbly tops and bottoms of the flows. These lavas and their blocky tops are each usually about 10 to 15 ft. thick. Tuff and scoria, although sometimes in thicker horizons, are definitely a minor constituent except where there have been local secondary centres. In exposures on the slopes of the Peak, scoria and ash horizons are much more important, frequently being 50 to 100 ft. in thickness and much more numerous. Some of these pyroclastics have been derived from secondary eruptive centres, but a high proportion of the main cone as a whole seems to be pyroclastic. It is likely that the slope of the central cone is largely determined by this steeply inclined ash and scoria material, while the slope of the Base is determined by the fluid lavas. Some of the lavas have come from secondary centres on or near the Base, and others have flowed down from the central crater, or the higher secondary centres.

This suggestion is supported by the gradients of the slopes themselves. On the windward side of the island (west and north-west) there is a pronounced change in gradient from 28° on the upper slopes to 11° below 3000 ft. In contrast, on the leeward side, the change in gradient is relatively constant from 22° on the upper slopes to 15° below 3000 ft. This can be attributed to a predominantly westerly wind carrying the ash to leeward.

The distinction in slope is even more apparent on most of the secondary eruptive centres, where a breached scoria cone will have outer slopes of about 30° while lava fields derived from the same centre have dips of about 5°.

The other major factor in determining the relative slopes of the Base and the Peak is the fluidity of the different lavas. Fluid basic lavas form thin flows no more than 1 ft. thick on the steeper slopes of the Peak, but thicken and accumulate on the flatter slopes below. More viscous trachyandesite lavas form steeply inclined flows more than 20 ft. thick on the higher slopes, and are not seen on the Base. Dunne (1941) has suggested that the upper slopes of the Peak are chiefly of more viscous lavas. However, basalt flows seemed more numerous, but not nearly so conspicuous, the trachyandesite lavas forming prominent, thick formations of pale colour, along the crests of ridges.

2·1·3. *The Main Cliffs*

The cliffs descend from the Base either to the shore or, in places, to the fringing coastal strips about 100 ft. above sea-level. Nowhere do the cliffs descend directly to deep water, the shore nearly always having a few yards of angular fallen blocks or of more rounded boulders and cobbles between the foot of the cliff and low-water level. Sandy beaches are few and usually transient. The cliffs are never vertical for their entire heights, there being few sheer drops of more than 1000 ft.

The cliffs are highest on the windward side, the north-west, where they rise to 3000 ft. above sea-level. The western side in general has cliffs of about 2000 ft. Going eastward, the cliffs diminish in height to 1500 ft. on the north-east and south-east sections, and only 600 to 800 ft. at the extreme east (Sandy Point). The cliff height seems independent of whether or not there is now a fringing coastal strip.

Marine erosion appears to be the sole cause of the cliffs, and there is no evidence of an origin by faulting. As discussed later, the coastal strips appear to have been formed in places by lava flows from secondary centres and are not down-faulted portions of the Base. The lavas of the coastal strips are thicker and more continuous than those of the Main Cliffs immediately behind. Where the cliffs have been protected from marine erosion by coastal strips, grass-covered, talus slopes are developed on the lower half of the cliff, the upper part being as steep as elsewhere but usually more densely vegetated.

The island could have acquired its present cliffed form in two ways. It might once have been much larger with the cone sloping right down to the sea, and with the sub-aerial and submarine slopes continuous; the cliffs would then be a subsequent feature. Alternatively, the island may never have been much larger, but may have grown progressively higher by addition of further volcanic horizons and been continuously trimmed back by marine erosion as it grew. Profiles of the submarine and sub-aerial topography are shown in figure 5. Though the data are not really adequate, it appears that there is no erosion platform, but that the water deepens fairly regularly off-shore. The cliffs are a definite step, not a nick in the profile. This would support the suggestion that the island has grown higher, but not been much larger, and that probably it has been 'cliffed' since it was formed.

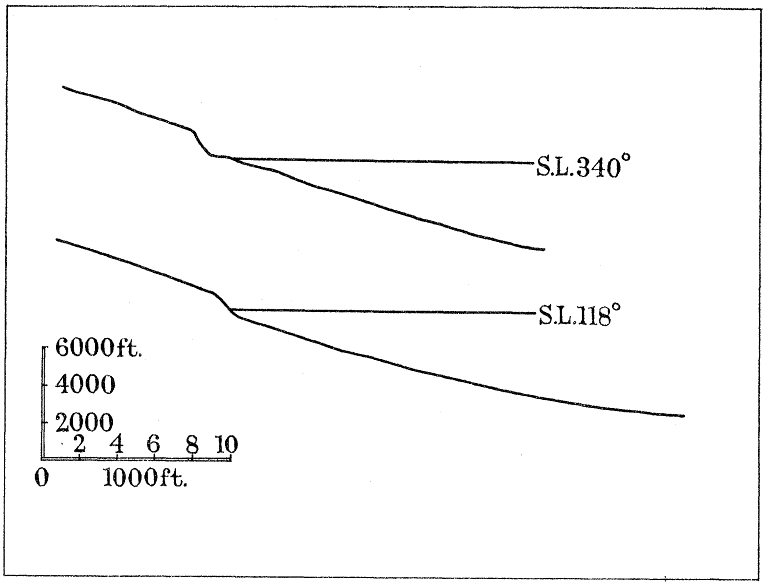

FIGURE 5. Continuous submarine and sub-aerial profiles.

This would be expected if the island has grown gradually, and been subject to continuous marine erosion throughout its history. This is in distinction from the neighbouring islands of Inaccessible and Nightingale, where the sea floor does not drop away uniformly from the shore, but where there is a well-developed platform. In places, the water is only 100 fathoms deep, even 3 or 4 miles off-shore. These islands appear much older than Tristan. Their volcanic activity and construction have ceased so that the normal effects of marine erosion in developing an extensive wave-cut platform, are the predominant features.

2·1·4. *The Coastal Strips*

There are four Coastal Strips, between the foot of the Main Cliffs and the sea. The largest, the Settlement area, on the north-west of the island, is over 4 miles long and nearly 1 mile wide in places. At Cave Point, there is a strip about 1 mile long and $\frac{1}{2}$ mile wide with an adjoining strip around Stony Hill about $1\frac{1}{2}$ miles long and $\frac{3}{4}$ of a mile wide. The strip at Sandy Point is much narrower, about $\frac{1}{4}$ mile wide and 1 mile long.

All of the strips have been subject to marine erosion, and are themselves cliffed along their seaward margins. In general the strips slope gently seaward, the upper surfaces having been modified by alluvium washed down from the Main Cliffs above. The Settlement area, especially, has its inland portion covered by a series of coalescing alluvial fans, some of which have been dissected. These do not always extend to the seaward margin of the strips, and their cliffed margins expose lava with no or little alluvial cover. In addition to the slope seawards, the strips often slope away from secondary ash centres. For example, the Seal Bay platform (Cave Point) slopes east-south-east at about 4° from Hackel Hill while south-west from Hillpiece, the sea-cliffs diminish in height from nearly 100 ft. at Boat Harbour Bay to 30 or 40 ft. near Burntwood.

2·1·5. *Drainage*

As would be expected from the topography, the Peak and Base are dissected by a series of radial valleys. Streams flow in these valleys only after heavy rain, and even then the stream may not reach the sea, but disappear into the permeable bedrock. Usually there is a complete lack of water in all the main valleys, despite a rainfall of up to 200 in. a year. The only reasonably permanent flow is in a stream from a group of springs at the base of the Main Cliffs near the Settlement and 100 yards to the west of the new eruptive centre, and in very small streams flowing across the peaty slopes of the Base.

The islanders distinguish between two types of stream valley, 'Gulches' and 'Gutters': gulches are the large valleys that can be traced from the Peak to the sea. On the slopes of the Peak they are usually V-shaped, but sometimes have narrow gorges if cut in lava or in cemented or welded scoria. They are commonly 100 to 200 ft. deep. Across the Base, the gulches are steep-sided, flat-bottomed trenches 30 to 100 ft. deep and 50 yards or more wide. Sometimes terrace remnants are preserved. The stream bed itself is usually narrow, perhaps 8 to 10 ft. across. Waterfalls are frequent, both on the Base and Peak, usually 20 to 30 ft. high, often the thickness of one lava flow and one scoriaceous or rubbly top. The lip of the fall and the plunge pool are always in solid lava. At least on the Base the streams seem to degrade largely by the headward retreat of the falls. On the Base the sides of the gulches appear to be fairly stable and are covered with tree fern, grass or island tree. Usually the floor of the gulch is also covered with vegetation, apart from the actual stream channel.

'Gutters' are narrow gullies, carrying very small permanent streams that rise on the Base. They do not extend up the Peak slopes. The gutters have no loose gravel floors but stable, vegetated or mossy stream beds. They may be shallow, in the peat or soil horizons, but sometimes are 15 to 20 ft. deep with near vertical walls and lava outcrops in the floor. However, they appear to be sealed from leakage by soil or peaty debris so that the streams continue to flow or to hold water even in dry weather. In places, the streams disappear into sinkholes in rubbly lava horizons. The streams in the gutters never reach the bottom of the Main Cliffs.

The difference between gutters and gulches seems to depend on whether the stream rises on the Peak or on the Base. On the poorly vegetated Peak, runoff is rapid and the scoriaceous and rubbly materials are readily eroded. The stream beds are covered with gravel which prevents any sealing of the permeable horizons with peat or soil. Water flows only after heavy rain, when considerable transportation of gravel and sand may occur. Streams rising on the Base have no access to easily eroded scoria. Gradients are gentler, and rapid runoff is prevented by the thick vegetation and moss. The erosive power of the stream is almost nil, especially in the absence of a suspended load of abrasive gravel.

The stable stream bed permits the sealing of permeable horizons by soil and vegetation so that stream flow is nearly permanent.

The amount of gravel present in the gulches varies widely from place to place. The western streams, e.g. First, Second and Third Gulches, have stream beds that are relatively free of fine gravel, the stream floor consisting of solid lava or large rounded pebbles and boulders that are relatively stable. Farther south, in Gipsy's Gulch, the stream has a wide bed covered with fine scoria and lava gravel, much of it angular and not abraded. This scoria has been derived from the several secondary centres and thick scoria horizons along the sides of the gulch.

All the valleys across the Base terminate abruptly at the Main Cliffs, as hanging valleys, each stream descending by a series of waterfalls. The individual falls are often several hundred feet high, frequently incised in narrow gorges, cut back into the edge of the Base. However, these gorges and high falls rarely extend more than 100 to 200 yards back from the edge of the Base. Above this point, the streams are in gulches or gutters of normal depth.

This abrupt change in gradient at the edge of the Base is at first sight surprising, since one would expect down-cutting of the stream bed to be rapid enough to keep pace with the recession of the cliffs by marine erosion. This might be regarded as evidence for a very recent origin of the Main Cliffs by faulting. However, the failure of the streams to cut down is thought to be due largely to the extremely easy underground drainage as streams that flow only a few days each year do not have much opportunity to erode their beds.

At the foot of the Main Cliffs, alluvial fans sometimes develop, especially on the coastal strips; often such fans have been incised by the streams. Although the larger gulches continue across the coastal strip as gullies, the smaller streams soak away into the permeable horizons so easily that no gulch forms, and the coalescing alluvial fans are not dissected but continue to grow. At the sea-cliffs fringing the coastal strips, the gulches again descend by a series of waterfalls, though in a few cases the gulches are graded down to sea-level.

Springs are seen in several places on the island. Even on the higher slopes of the Peak a favourably dipping impervious lava horizon may cause a slight trickle of water to appear locally at the surface, while minor springs occur at the junction of the Base and the Peak. Extensive tracts of swampy ground occur upslope of some of the secondary volcanic centres on the Base. The main springs are all at the base of the Main Cliffs, often at sea-level. A prominent group of springs behind the Settlement, 100 yards to the west of the new eruptive centre, provide a water supply for the village, and was the source of the only significant permanent stream. These springs have a flow of about $\frac{1}{2}$ cusec. Even more powerful springs emerge on the beach below, at the western junction of the new lava and the coast, these having an apparent volume of about 5 cusec.

Springs were also observed between tidemarks on the north-eastern end of Stony Beach Bay and near Bull Point.

2·1·6. *Erosion and denudation*

The regions of the island being most actively eroded are the sea-cliffs and the upper slopes of the Peak. Above 4500 ft., there is little vegetation or soil, the ground surface consisting of outcrops of lava or of a surface of angular lava fragments and scoria. The high proportion of scoriaceous material present permits easy erosion. Higher still there is no vegetation except moss, which grows only on the more gentle and stable inner slopes of the crater and on outcrops of solid lava. This and the fresh appearance of rock fragments indicate that the surface is unstable and in frequent movement, as would be expected on slopes as steep as these. Solifluction phenomena occur at about 6000 ft. in the form of stone stripes (figure 30, plate 20). Here, the angular gravels are sorted into parallel bands of different size, pointing downhill. From this region to the summit there are no pronounced gulches, probably due to the rapid downslope movement of the debris overshadowing stream erosion. Between 4500 and 6000 ft., the original uniformly inclined surface has been completely dissected by erosion, leaving sharp ridges between the gulches, often capped by lava.

Further downslope the vegetative cover prevents the downhill movement of talus, and the chief signs of erosion are in the walls of the gulches, which frequently show scars of rock falls. Sometimes narrow strips of the original interfluves are preserved between the gulches.

On the Base there seems to be little active erosion, apart from the walls of the gulches, especially near the cliff edge, where rock falls have accompanied the incising of the streams. Even the scoria cones on the Base are usually well preserved, since the extreme permeability of the rocks precludes surface runoff. However, some of the older cinder cones are extremely dissected with the development of typical badland topography (see figure 36, plate 21), a feature recorded by Cotton (1944). This feature is exceptionally well displayed on the north-west corner of the Base at Nellie's Hump.

The Main Cliffs are usually covered with vegetation except where they are subject to marine erosion and in restricted narrow vertical strips where it has been removed by landslip, e.g. behind Hillpiece. Otherwise, the chief places of active erosion are where the streams descend.

On the coastal strips, some soil erosion occurs, due to removal of the grass cover. The original tussock grass has been entirely replaced by short grass since the introduction of grazing animals. At Stony Beach, where over-grazing is evident, sand blown from the East Beach is encroaching on the grassland and forms extensive superficial deposits. On the Cave Point coastal strip, the grass cover is thin in places, especially near Cave Point, and sheet erosion seems prevalent. Near Cave Point this is probably assisted by spray breaking across from the western cliff, the water running downhill towards Seal Bay.

Wave attack is severe on all sea-cliffs, the debris being rapidly removed from the base of the cliffs, either withdrawn to deeper water by the waves, or transported by long-shore current usually from west to east. The importance of long-shore drift is illustrated from the new lava field. Wave attack on the sea margin in February and March caused rapid retreat, probably of 20 to 30 ft. or more in places, sometimes with a pebble beach forming in front. In the same period a boulder beach or bar formed extending from the eastern end of the lava front eastwards to merge with the original coastline at Pigbite. The bar, 150 yards long and 30 yards wide, enclosed part of the sea to form a lagoon (figure 67, plate 29). The bar consisted of material derived entirely from the new lava and ranging from rounded $\frac{1}{2}$ in. fragments to angular boulders 3 to 6 ft. across. The coarsest material was at the western end of the beach with fine gravel at the eastern end. There was no trace of this bar in early February, so that it was built in a period of less than 4 weeks. Between March and September 1962, a similar bar 200 yards long was built up at the western end of the lava front. At the same time, indentations in the new lava front had been filled by gravel beaches (H. G. Stableford, personal communication).

The predominantly west–east currents and wave movements that built these boulder beaches also account for the accumulation of sand at Sandy Point where there are extensive sand beaches and a shallow sandy bottom offshore. Elsewhere sandy beaches are few in number and very limited in extent, except in the Seal Bay–East Beach region, where there are sandy stretches of several hundred yards. Big Beach, now almost covered by the new lava, was the largest sandy beach on the island.

The form of the cliffs and foreshore is determined largely by the nature of the lava flows in the cliffs. The succession of horizontal lavas of the main sequence forms high vertical cliffs. Where thick flows with good columnar jointing are exposed at sea-level, wave attack is more rapid and bays have developed, e.g. at The Hardies, Boat Harbour Bay, the bay south of Crawford Point, and Seal Bay. Stacks, sea-caves and arches also are present in these areas of pronounced columnar jointing.

2·1·7. *Secondary eruptive centres*

Although the secondary centres are prominent physiographic features, it is more convenient to discuss them in detail in a later section.

2·1·8. *Faulting and intrusion*

Major folding and faulting do not occur, though small-scale slump structures and adjustment fractures were seen in some tuffaceous horizons. Dykes occur in sections of the Main Cliffs, and as upstanding remnants in the easily eroded ash of the Peak, where they form walls as much as 60 ft. high. The dykes nearly always appeared to be radial and presumably were injected along lines of weakness or fracture caused by swelling and deflation of the volcano, before and after eruption. Intrusive necks are common; one, immediately behind the Settlement, suffered major rock falls in the period of earth movement preceding the new eruption. These necks all have pronounced vertical jointing and form vertical cliff faces. Trachytic necks on the Peak are prominent, standing well above the surrounding scoria slopes.

2·2. *The primary volcano*

This section is concerned with that part of Tristan bounded by the Main Cliffs and the surface of the Base and the Peak, but excludes the surface parasitic centres, the fringing coastal strips and the 1961 eruptive centre which are decribed separately.

Excellent exposures of the main sequence are to be seen in the cliffs that bound the island and also on the Peak; these two regions are separated by the densely vegetated Base where exposures are found only in the gulches. In the Main Cliffs the oldest rocks of the island are exposed whilst on the Peak the surface geology reflects the most recent activity associated with the central conduit.

2·2·1. *The Main Cliffs*

With the exception of two short sections, impassable except in the calmest weather, the Main Cliffs were examined at close quarters from the narrow foreshore. In most places it was impossible to climb more than 100 ft. up these near-vertical cliffs and descriptions given hereafter, unless stated otherwise, are limited to exposures seen near sea-level. However, an excellent impression of the structure and composition of the Main Cliffs can be obtained from a boat lying off-shore. Examination of all the cliffs was made in this manner. In many cases structures and rock types seen high on the cliffs have their parallel at sea-level and most, if not all, of the problematical structures were examined in detail.

The immediate impression given by the exposures in the Main Cliffs is one of horizontality; the normal sequence is a horizontal alternation of grey lava and reddish-brown fragmental layers cut by occasional vertical dykes. However, in places the sequence is replaced by thick, inclined deposits of red pyroclastic material. It is apparent that the rocks forming the Main Cliffs were derived from many centres. The apparently horizontal units have a gentle seaward dip parallel to the overlying Base and probably issued from the central conduit. The red pyroclastic material was derived from localized secondary cinder centres on the flanks of the main volcano. Throughout its development Tristan has consisted of a central vent with numerous parasitic cones on its slopes. This is confirmed by the present-day topography of the island, where over thirty secondary centres are to be found on the flanks of the central cone. The rocks exposed in the Main Cliffs will therefore be described under two categories: central vent material and that derived from the parasitic centres. It must be stressed that the junction between these two is by no means simple. Indeed, as would be expected, there would be every indication that extrusion from the main vent was accompanied or interspersed by activity at the parasitic centres and that the products of the two interleave.

(*a*) *Central vent material.* The cliff succession consists of horizontal superimposed grey lava flows. Normally between solid lava horizons are reddish-brown layers of rubble or fragmental material, representing the blocky tops and bottoms of the flows beneath and above. True pyroclastic material also occurs within this sequence and forms 15 to 20% of the total thickness. From a distance it is often difficult to distinguish between the pyroclastic horizons and the finer rubbly layers. Although from the sea most of the Main Cliff sections appear to contain about 100 horizons, examination of the few climbable sections reveals that this is a considerable underestimation. 140 units are present in Gipsy's Gulch, and about 150 in Plantation Gulch. It is probable that an average of about 150 units are exposed in each 2000 ft. cliff, that is, about sixty lava flows with associated rubbly horizons, together with subordinate pyroclastic layers.

These lavas vary in thickness from 1 to 21 ft., the majority being between 8 and 10 ft. thick. Many of the thinner flows are less than 100 ft. wide, whilst a few of the thicker lavas have been traced for over $\frac{3}{4}$ mile along the cliff face. Invariably, the lower surface of a flow is uneven, conforming to the irregularities in the underlying surface. In most cases this lower portion of an extrusive unit is brecciated; sometimes the lower part of a flow is chilled against the underlying rock. The degree of chilling varies depending on the composition of the lava and also on the nature of the underlying material. It is usual for fine-grained, non-porphyritic rock to have a basal chill zone of 1 to 2 in. whilst with the basic, highly porphyritic lavas this zone may be up to 6 in. thick. It was also noted that when a lava was extruded directly on top of another solid lava, the chilling was more extensive than when the lava had flowed on to pyroclastic material. In the absence of other data, it must be assumed that this is due to the lower thermal conductivity of the pyroclastic material. In some cases when the lava has passed over unconsolidated pyroclastic material, pieces of this debris have been caught up and are preserved as xenoliths within the bottom 18 in. of the flow.

Generally the lower half of the solid lava is massively crystalline with pronounced columnar jointing often developed in flows over 15 ft. thick. In the upper part, the columnar jointing often gives way abruptly to near-horizontal, lamellar flow planes. Most flows, irrespective of their composition, show marked upward increase in vesicularity. Spherical vesicles are common in the middle portion whilst towards the top they are usually elongated vertically and often bent over in the direction of flow. When the rocks are porphyritic, the megascopic crystals often show a near-horizontal flow banding. This feature is present in most of the lavas containing mafic phenocrysts and in some of the feldspar-phyric flows. Very occasionally, within individual thick flows are flat cavities up to 2 ft. in height and 6 ft. in width and disappearing back into the cliff face for as far as could be seen. Invariably these cavities are lined with *filamented pahoehoe* (cf. Wentworth & MacDonald 1953) and they probably represent small lava tunnels formed by the withdrawal under gravity of fluid lava from the centre of a mainly solidified flow.

The surface structures of the lavas are very variable, and are dependent essentially on the fluidity of the individual flow and thereby on its composition. Most commonly the surface of the basaltic flows is a reddish-brown rubble, usually 3 or 4 ft. thick, consisting of abraded fragments of lava together with broken pieces of *pahoehoe* or *ropy* lava, and often cemented by thin driblets of lava. An excellent example of this type of lava surface is exposed at the south end of Sandy Point, where a grey, feldspar-phyric basalt, immediately above the foreshore, has a pink fragmented top that varies from 1 ft. to 18 in. in thickness. Generally, the tops of the more basic, highly porphyritic lavas are only mildly blocky although the upward increase in vesicularity is still well marked. In isolated cases, more especially with the highly porphyritic basic lavas, the upper surface is smooth, the top of the flow being marked by an increase in vesicularity and the presence of the bottom chill zone of the overlying lava.

Well-developed examples of *pahoehoe* or *ropy* lava surfaces can be seen in the lower reaches of Fem's Gulch about 200 yards from Snell's Beach. Here, a number of thin flows of black vesicular basalt interbedded with red volcanic ash have beautifully developed ropy tops (figure 90, plate 33). On Tristan this type of surface seems to be best developed on the thin flows which, by their very thinness, would suggest that they were very mobile. The 'ropes' are in all cases orientated across the direction of flow and are arcuate, convex in that direction. In all outcrops of this type the individual 'ropes' varied in diameter from 1 to 4 cm and were encrusted with a thin brown coating. Generally, the lava is extremely vesicular, these cavities being elongated in the flow direction and plicated to conform with the ropy surface. Small ridges on the surface of the lava, at right angles to the 'ropes', are the surface expression of the orientation of the vesicles.

It is evident that there have been periods of quiescence during the volcanic evolution of Tristan, for frequently an undulating erosion surface can be seen to cross several flows. These surfaces are sometimes accentuated by thin layers of red volcanic ash; such a surface can be seen in the Main Cliffs between Big and Rookery Points. Non-transgressive erosion and weathering surfaces are less obvious but still quite common. For instance, at the south end of Sandy Point in a highly porphyritic basalt, the upper 9 in. are weathered, the olivine and pyroxene phenocrysts being replaced by secondary minerals and the once glassy groundmass has been devitrified. In this context the decomposition can be due only to weathering.

Individual flows range in composition from fine-grained equicrystalline trachybasalts through basalts, porphyritic olivine- and feldspar-phyric basalts to coarsely porphyritic ankaramites. Trachybasalt appears to be the dominant rock type (see figure 9); porphyritic and non-porphyritic basalts are common. Ankaramite, with abundant and conspicuous, pale-green olivine and black titanaugite phenocrysts, is relatively rare and occurs as thick, extensive columnar jointed lavas. Detailed petrographic descriptions of these rocks are to be found in § 2·5, pp. 493 to 501 and analyses in table 6, pull-out facing p. 520.

There is no definite evidence that the pyroclastic material interbedded with the lavas was derived from the central vent. Some of the fragmentary material can be traced to explosive parasitic centres exposed in the Main Cliffs; where this is not possible the source of the pyroclastic debris is in doubt. The central vent is, on an average, only 4 miles from the Main Cliffs and pyroclastic debris from this source could, on many occasions, have extended for this distance under suitable wind conditions. Although thick, impersistent lenses of coarse material most probably originated from nearby parasitic centres, the finer pyroclasts found in extensive horizons probably came from the central vent. These horizons of finer material are conspicuous by their bright orange-red colour and have a considerable lateral extent (over $1\frac{1}{2}$ miles in some cases) although rarely more than 3 ft. thick. This thickness is relatively constant in marked contrast to the pyroclastic debris from local centres which varies rapidly in thickness. The material consists of basaltic ash often with small euhedral crystals of pyroxene and with a grain size of less than 2 mm.

The bottom contact of these horizons is often an erosion surface, sometimes transgressive, and irregularities in this surface are infilled by the overlying ash. The thinly bedded ash shows gentle cross-bedding suggestive of aeolian deposition under varying wind conditions. Fluting, with $\frac{1}{2}$ in. relief is common on the upper surface and may be caused by surface run-off.

At the base of the Main Cliff in the central part of Stony Beach Bay is a 200 ft. thick deposit consisting of large angular boulders set in an unsorted, finer-grained matrix. In places, at beach level, this deposit could be seen to rest on thinly bedded tuffs. A thick deposit of yellow tuff, dipping seaward at 32°, overlies this material. The lateral contacts are masked by talus and soil but the normal sequence of horizontal lavas reappears 300 yards to the north-east. The shape of the deposit cannot be defined from the visible outcrop but it would appear to be irregularly lenticular with a maximum thickness of 200 ft. and a maximum width of 600 yards.

The deposit consists of large angular boulders of grey lava and yellow tuff up to 3 ft. in diameter set in a matrix of smaller fragments of vesicular lava, scoria and ash ranging down to sand-size particles. No bombs were seen. In places, rude alinement of the larger boulders could be seen; this alinement appeared to be inclined seawards at about 30°.

The poor sorting and the angularity of the fragments indicates either a glacial or lahar origin. The absence of other glacial phenomena and the geological environment support an origin by lahar or volcanic mudflow, perhaps from a central crater lake.

(*b*) *Parasitic centres.* Parasitic centres within the main sequence are common and a number are exposed in the Main Cliffs. The largest centres are marked on the accompanying geological map and are: behind the Settlement, at Spring Ridge, Stony Beach Bay, Sandy Point and West Jews Point. Further, similar centres are exposed higher in the Main Cliffs but are not depicted on the geological map as their limits are not exactly known. The fragmental deposits from these centres have many features in common. Both the upper and lower surfaces of the pyroclastic horizons are usually extremely sharp and especially prominent when in contact with solid lava. In some horizons there is no stratification of the pyroclastic debris whilst in others, especially where there is variation in the size of the fragments, a layering is present. Generally, the finer volcanic debris is well bedded whilst the coarse material is usually without discernible structure. Individual layers frequently show grading from coarse material at the bottom to fine at the top. The material of these horizons can be subdivided into that originating directly from molten magma and xenoliths. The originally molten material has formed red basaltic scoria of varying size together with volcanic bombs of all shapes and sizes. It is not thought necessary to describe this pyroclastic material in detail as it is similar in all respects to material described elsewhere (Rittmann 1962; Wentworth & MacDonald 1953). Xenoliths can again be subdivided into angular fragments of extrusive material similar to the contemporaneous lavas and plutonic fragments brought up from depth. Occasionally found within the pyroclastic debris are large, well-rounded boulders of varying types of lava; it seems most probable that these are boulders of older lava flows, rounded by sub-aerial erosion, and subsequently caught up within the pyroclastic material.

Varying states of compaction are displayed by these pyroclastic horizons. In many cases the lower layers tend to be slightly welded whilst the upper part of an individual layer is often poorly consolidated. This feature is general and not dependent on the horizon's position in the sequence. Often found within the pyroclastic layers are tenuous driblets of lava.

Where the conduits for these centres are exposed, for instance behind the Settlement and at Spring Ridge, they are roughly circular in plan, varying in diameter from 50 to 100 yards and usually consist of trachybasalt. In section, the margins are well defined and usually near vertical. In some cases, a thick conduit exposed in the bottom of a section can be seen to branch or divide upwards into minor necks or dykes; i.e. in Hottentot Gulch at the base of the Main Cliffs. All display pronounced vertical jointing which is probably responsible for their occurrence as vertical cliff faces.

Apparently associated with some of the parasitic centres are thick lavas of fine-grained, columnar-jointed trachybasalt characterized by strongly contorted flow-banding (figure 89, plate 33). These lavas sometimes attain thicknesses of 300 ft. and rarely exceed 350 yards in width. In cross-section, normal to the direction of flow, they are usually lenticular, although the sides of the lenses often interdigitate with pyroclastic horizons. These lavas appear to occupy pre-existing valleys and depressions.

These parasitic centres show many features in common. Two particularly well exposed and especially instructive centres are at Sandy Point and behind the Settlement and will be described in detail.

The Sandy Point parasitic centre extends from Carlisle Beach southwards to The East End of Sandy Point, a distance of just over 1 mile. Within this area, excellent exposures are to be found in Big Gulch, the Main Cliffs to the north and south of Big Gulch, at Sandy Point itself and in the lower reaches of The East End of Sandy Point Gulch.

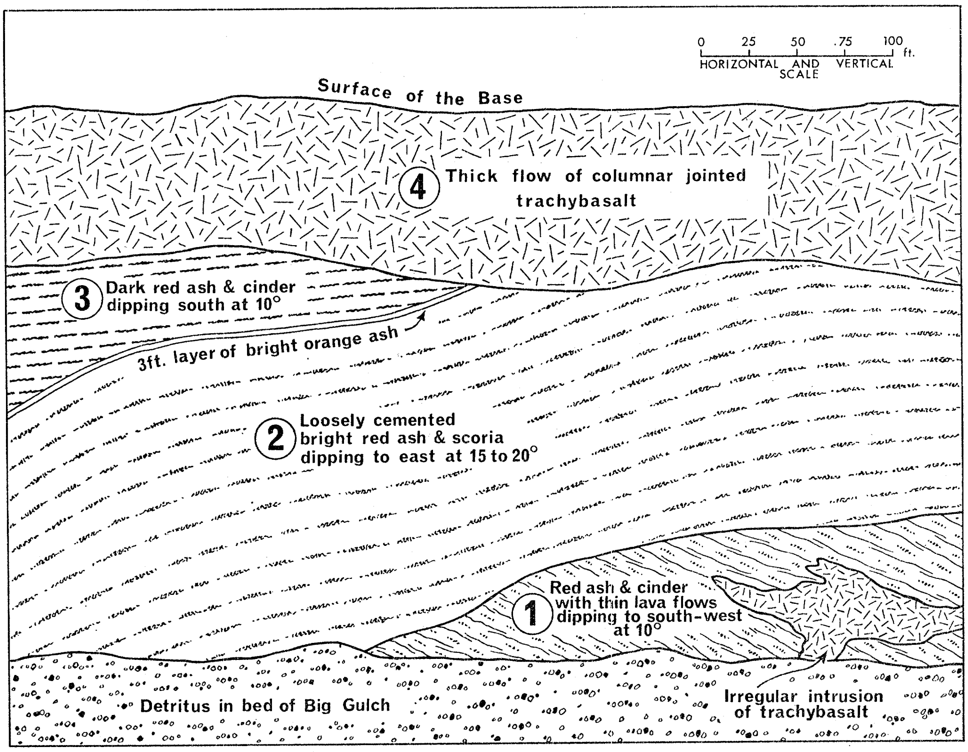

Figure 6. Sandy Point parasitic centre: sketch of south bank of Big Gulch.

Undoubtedly, the eastern part of this centre has been removed by marine erosion; the western boundary is masked by younger extrusive material. This pyroclastic complex had many centres and the area is considered to be a series of cinder cones intermingled with thick lensoid masses of grey, fine-grained trachybasalt lava of limited areal extent (figure 28, plate 20). The interrelationship of the numerous cinder cones is best displayed in the south bank of Big Gulch from its mouth to about a $\frac{1}{3}$ mile inland. Here, in a near-vertical section some 300 ft. high, at least three pyroclastic units are displayed. The relationship of these units is depicted in figure 6 which is a diagram of the south bank of the Gulch.

These three superimposed extrusive units undoubtedly represent material derived from three different cinder cones. The lower unit (1) consists of bright red scoria horizons interbedded with thin, highly vesicular flows of olivine-basalt. The scoria contains angular fragments of lava and occasional volcanic bombs in a poorly cemented matrix. The attitude of this unit, which dips at 10° to the south-west (220°), is accentuated by the interbedded thin lava flows. Overlying unit 1, and forming the majority of this section, is a series consisting of alternating fine ashes and tuffs about 120 ft. thick and inclined at between 15° and 20° to the east (100°). The material in this division is very similar to that in unit 1 but no interbedded lavas were seen. The sharp contact between units 1 and 2, formed by the differing attitude of the beds, is not one of marked lithological change. At the top of unit 2 there is a thin, 1 to 3 ft. band of bright orange volcanic ash which in turn is overlain, in part, by a third unit consisting of dark red volcanic debris interbedded with thin lavas all being inclined at 10° to the south (170°).

The dips of all these units have a southerly component and the material must therefore have issued from three separate vents that lay to the north of the outcrop described. The multiplicity of the pyroclastic centres within this complex is, no doubt, much greater than the three here described. In other sections on the north bank of Big Gulch, in the cliffs between Big Gulch and The East End of Sandy Point, pyroclastic material is exposed, but nowhere can the position of the vents be so clearly deduced as in Big Gulch.

Capping the Big Gulch section described above is an extensive lava flow about 100 ft. thick. This mass displays well-developed columnar jointing and although not directly accessible, it can be seen from fallen blocks to consist of a fine-grained trachybasalt with intricately folded flow-banding. Excellent and easily accessible exposures of these lavas can be seen in the foreshore at Sandy Point and in the entrance to The East End of Sandy Point Gulch. Although the size of these flows is very variable they all seem to have a roughly lenticular cross-section normal to the direction of flow. In all cases the rocks present are very similar, having extremely well-developed flow-banding. Columnar jointing is present in most of the thicker parts of the flows; elsewhere the lavas are usually massive or have a widely spaced random joint pattern.

A remarkable feature of these flows is their relationship with the enclosing pyroclastic debris. Generally there is no evidence whatsoever of chilling. Further, the fragmental material underlying the lava never shows signs of baking and the only apparent effect of a superimposed lava is to produce a narrow 2 to 6 in. band of shearing in the immediately subjacent debris. Occasionally, the lowest 6 in. of the lava displays closely spaced lamellar joints parallel to the bottom surface.

When bedding is present within the pyroclastic debris, the lavas always seem to conform to this layering. It is also evident that in many cases explosive activity continued throughout the extrusion of the lava.

The Settlement parasitic centre is exposed in the lower part of the Main Cliffs immediately behind the Settlement and also in Hottentot Gulch and is completely overlain by horizontal lavas of the primary volcano. Material from this centre extends for 1 mile to the south-west of the 1961 volcano to just south of Little Sandy Gulch, and is exposed in the Main Cliffs to a height of 1500 ft.

In many ways this centre is similar to that at Sandy Point which has just been described. The variety of pyroclastic material present is similar and in both centres there is a complexity of numerous individual cones. It is not intended to describe fully the pyroclastic debris but to describe features which are not displayed by the Sandy Point complex.

Immediately behind the village, an 800 ft. high volcanic neck of grey, vertically jointed trachybasalt is exposed. This mass, which is also exposed on the eastern side of Hottentot Gulch, is 350 ft. in diameter and is thought to represent the main conduit for the cinder centre. Other similar but smaller conduits are exposed in the western bank of Hottentot Gulch at 1100 and 1500 ft. The pyroclastic material surrounding these conduits has a radial inclination and it is apparent that this complex had at least three centres which were probably active at different periods. Branching from the largest conduit are thick, irregular, near-horizontal intrusives of similar grey trachybasalt, as well as thin, vertical veins and dykes. These are seen in the Hottentot Gulch exposures.

An interesting feature of this centre was that some of the pyroclastic debris appears to have been deposited under water. Exposures in the quarry, above Jenny's Watrun, from which the islanders get building stone, contained a 20 ft. horizon of coarse yellow agglomerate with flattened brown-black lava fragments up to 1 ft. long. Farther west, this deposit is capped by 4 ft. of water-deposited tuff. Some exposures of the tuff horizon are extremely well bedded and show small-scale current-bedding and washout features. Some of the beds are well sorted, often containing well-rounded pebbles and in places small spicules of brown organic matter. These stratified deposits appear to be too well sorted to be of alluvial origin and were probably laid down in a near-shore marine environment. The absence of fossils is to be expected in view of the paucity of the local molluscan fauna.

Lying unconformably beneath these sedimentary horizons is a 10 ft. vertical outcrop of a hard, pale-grey, vertically banded trachyte mass with a pronounced weathered surface. A specimen from this locality, identified as an alkali feldspar trachyte, has been analyzed (sp. 31, facing p. 520) and described in detail (p. 500). Some 10 yards to the west of this occurrence, but separated by surface debris, is an outcrop of phonolitic alkali feldspar trachyte (sp. 30 analysis facing p. 520, description p. 500). It is most likely that both these specimens belong to the same mass which is probably a volcanic neck or plug that was eroded prior to the deposition of the overlying sediments.

2·2·2. *The Base*

Between 2000 and 3000 ft. the surface of Tristan has a gentle radial inclination of about 8°. This area, known as the Base, is almost completely mantled with low-lying, dense vegetation developed on a thick soil cover. Rock exposures are only seen in the deeper gulches. Examination of these exposures indicates that the flows from the central vent are inclined at, or slightly less than, the slope of the overlying land surface and that the rock types present are the equivalent of those more adequately exposed in the Main Cliffs. As the lavas and interbedded pyroclastic material are so nearly parallel to the overlying surface, and the gulches are rarely more than 100 ft. deep, the evidence concerning the vertical succession is limited. It was possible in some instances to see that there was no significant variation in the type of flow with increasing distance from the central vent.

The gulch floors are often stepped every 200 to 300 yards by small waterfalls usually 20 to 30 ft. high. Each fall exposes one or two lava units with fragmental horizons between. Upstream of the falls the gulch floor is usually the upper surface of the fall-making flow until the next fall is reached. Moving upstream, successively higher lava horizons are exposed in the gulch floor by each waterfall. In no case was it possible to trace an individual flow for more than $\frac{1}{4}$ mile. Although the lower surface of most of the lavas is extremely irregular, there is no apparent variation in the thickness of an individual flow across the Base and certainly it was not proved that the lavas thinned markedly in a seaward direction. Specimens taken from the same flow at intervals down a gulch section showed only slight variation in their modal composition.

In all the gulches examined there was a tendency for the proportion of pyroclastic material to increase as the Peak was approached. At the edge of the Base, directly above the Main Cliffs, pyroclastic material forms less than 20% of the sequence. At the upper limit of the Base, where this was discernible, pyroclastic material formed between 40 and 45% of the sequence.

2·2·3. *The Peak*

That part of the island above 3000 ft. is generally referred to as the Peak, though the term is also used to designate the highest part of the island, Queen Mary's Peak (6760 ft.).

Like the rest of the island, the Peak is built of an alternating succession of lava flows and fragmental horizons with a radial inclination. However, the proportion of lava to pyroclastic material is much lower, in some places lava being as little as 25% of the sequence exposed. The basaltic lavas tend to be relatively thin, sometimes only 1 ft. thick whilst trachyandesite flows exposed above 4500 ft. are often 30 ft. thick.

Basaltic flows do not form prominent features, being mantled in most cases by pyroclastic and talus material. The composition of these flows seems to be in no way different to those exposed on the Base and in the Main Cliffs. Near the summit, the pale-grey, trachyandesite flows are conspicuous, often capping the ridges between the gulches. These feldspar-phyric rocks, being only weakly jointed, resist erosion and are prominent. Retreat of their margins is caused largely by undercutting in the softer pyroclastic horizons beneath with the formation by collapse of a fringe of large angular blocks. Trachytic masses in the form of plugs occur in the summit crater and on its southern flank; these will be described later.

Pyroclastic material consists largely of red and black scoria, often containing bombs and sometimes interbedded with tenuous lavas. Although, from its radial inclination most of this material must have come from the central crater, much was derived from parasitic eruptive centres since the bedding is frequently horizontal or even centrally inclined; for instance, in Gipsy's Gulch at 4000 ft. and in East Molly Gulch at 3500 ft. secondary centres on the surface of the Peak do exist but are poorly preserved owing to the poor consolidation of the scoria and the rapid rate of erosion. These surface centres are described in more detail in § 2·3, pp. 470 to 481.

South of the summit at a height of 5400 ft. is a prominent plug, presumably the neck of a former secondary vent. It is a mass of hornblende-bearing plagioclase trachyte rising almost vertically above the talus slopes and possessing a marked vertical jointing (analysis 560 (table 6. facing p. 520); petrographic description p. 501). Below it is a lava flow of similar material.

At the summit is a well-formed crater partially filled by a shallow, freshwater lake.

The highest point of the island, Queen Mary's Peak (6760 ft.) is part of the crater rim.

The red and black scoria of which it is chiefly formed was derived largely from the summit crater itself, though the inclination of the scoria around Queen Mary's Peak suggests that this eminence was itself an eruptive centre.

The summit crater is roughly circular, about $\frac{1}{4}$ mile in diameter from rim to rim; the heart-shaped lake is in the south-eastern part of the crater floor and is about 100 yards across (see figure 29, plate 20). The water of the lake was cold and pure, with no indication of volcanic contamination. Nowhere does the crater possess precipitous walls; the slope into the crater is steepest below Queen Mary's Peak, which is about 300 ft. above the level of the lake. On the north and north-western sides, where the rim is only about 80 ft. above the lake, the crater walls are much less steeply inclined and the rim itself is less sharply defined. The crater walls are regular slopes of lava fragments, loose scoria and cinders broken by four rock outcrops. One of these, half way up the north-east wall is a plagioclase trachyte with marked vertical jointing and probably represents the remnant of a volcanic neck. The three remaining outcrops are all of leucite-bearing trachybasalt, again probably old volcanic necks, though it is possible that the small outcrop immediately to the south of the plagioclase trachyte mass and the similar one on the opposite side of the crater are relics of a single dyke, once continuous across the area now occupied by the crater. The elongate outcrop and jointing of the leucite-bearing trachybasalt on the south-western side of the lake is certainly suggestive of dyke form.

Slightly upstanding outcrops of massive lava are to be found at various points around the crater rim. Two such occurrences are the hornblende trachyte masses of Church Rock and the small feature immediately to its south.

Extending for 300 yards to the south of Queen Mary's Peak is a ridge, terminating in a gentle rise which is called Mount Olav on the accompanying geological map. This ridge is formed of red and black scoria and lava fragments and is, in all probability, a remnant of the original surface not yet eroded by the headwaters of Deep and Third Gulches which encroach on either side.

On the ridge directly behind Green Hill at about 4500 ft. is a thick mass of vertically jointed lava forming prominent crags and scarps. The upper part of this mass passes upwards into vesicular lava which in turn is overlain by pyroclastic debris. Where the base can be seen it lies on scoria and ash. Although the top surface is relatively flat the base is inclined inwards, the lava thickness increasing from less than 10 ft. at the outside margin to over 50 ft. at the innermost outcrop. In places, the vertical jointing has a dominant south-easterly trend with only weak jointing at right angles. Elsewhere, the jointing is columnar.

The central part of this body is a leucite-bearing trachybasalt (581) and is a massive blue-grey porphyritic rock with abundant small phenocrysts of pyroxene, plagioclase and a little olivine. In thin section the groundmass contains rounded spots of interstitial leucite together with plagioclase laths and grains of pyroxene and iron ore. The vesicular top (580) is a dark grey rock containing small phenocrysts of plagioclase and pyroxene. The groundmass consists of laths of plagioclase and grains of pyroxene set in a cloudy dark brown glassy matrix. Leucite is absent.

This mass would appear to have filled an earlier crater whose form is now preserved by its lower surface.

2·2·4. *The Dykes*

One of the most striking geological features of Tristan is the marked radial dyke swarm centred on the summit (see geological map). Over 90 % of the dykes mapped have a radial disposition, whilst a few are intruded at right angles to this pattern. Where the two intersect, the dominant, radial dykes are the younger. From the geological map it can be seen that the density of the dykes is highest on the Peak whilst numerous dykes are exposed in the Main Cliffs. The apparent paucity of dykes on the Base is probably due to the fact that this surface is a constructional and not an erosional feature.

With few exceptions, these intrusives are vertical or nearly so, vary in width from 2 to 20 ft. and are regular in their attitude. Dykes less than 4 ft. in width are often gently sinuous and can sometimes be seen to split only to reunite again a few feet higher up. In the Main Cliffs it is quite common to see the thinner dykes dying out vertically and in some cases, for instance behind the Settlement, they have a vertical extent of only 50 ft., being pinched out at both ends.

On the Peak, where denudation of the scoriaceous slopes has been intensive, wall dykes, conforming to the general radial pattern, form the most striking topographic feature. These dykes, usually between 6 and 10 ft. wide, stand out as much as 60 ft. above the surrounding red and black volcanic scoria and cinder, and can be traced, albeit intermittently, for hundreds of yards. The dykes are generally lighter in colour than the surrounding pyroclastic material and are often aproned by large blocks derived from the intrusion itself. The best examples of wall dykes are to be found on the eastern side of Cave Gulch, south of the summit (figure 32, plate 20).

In the Main Cliffs the dykes are clearly visible as they cut across the virtually horizontal extrusive sequence but their position is rarely accentuated by erosion (figure 31, plate 20).

Chilled margins are universally present, the extent of the chilling varying both within a single dyke and from one intrusion to another. There seems to be no correlation between the degree of chilling and the width of the dyke. In some cases, especially on the Peak, the more coarsely crystalline centre of the dyke has been eroded to a greater extent than the chilled margins. This phenomenon is not universal and in many cases is represented by no more than a slight medial depression. It was noted that, in some cases, the centre of a dyke was more closely jointed than the chilled margin, which would also explain the medial depression.

Baking of the host rock by the intrusives can only be seen where they cut pyroclastic material and in no case does this affect more than a few centimetres in the immediate vicinity of the dyke itself. In some instances, the contact between the dyke and the host rock is accentuated by red hematitic staining.

There is no difference in the petrography of the dykes and the lavas of the main sequence. Textural differences are slight; many of the dykes are finer grained than flows of the same composition. The range in composition, from ankaramite to trachybasalt is the same as that of the lavas of the main sequence.

2·3. *Secondary centres*

Over thirty eruptive centres are recognizable, forming prominent surface features on the island; they have no apparent preferred orientation except the 'Ponds' and the Cave Hill Group which lie along lines radial from the Peak. In addition, there are a very large number of earlier secondary centres, now partially eroded or buried beneath later flows (see § 2·2·1 (*b*)). The newer eruptive centres are characterized usually by prominent scoria mounds or lava cones, and most of them can be identified from aerial photographs (figure 25, 26, plates 18 and 19). Some of these centres possess a single crater whilst others are multiple. The centres are of four main types:

(1) *Explosion centres, consisting of a crater with little or no eruptive material around it.* The only explosion centres recognized are the 'Ponds', three lake-filled craters lying on the north-east of the Base.

(2) *Scoria mounds, in which all, or nearly all, the erupted material has been pyroclastic.* If early lava flows occur they are now hidden by scoria. Most of these centres consist of red and black scoria and cinders, often containing spindle bombs, and sometimes partly welded to give a relatively coherent agglomerate. In some cases the scoria may be hundreds of feet thick and the mound may have a diameter of several hundred yards. Some of the centres described under this heading may be really breached cones whose original form has been modified by extensive erosion.

(3) *Breached scoria cones with lava fields extending from the breached crater.* These are the most conspicuous and best preserved type of centre. In nearly every case, the breach is on the downhill or seaward side of the centre, and hummocky lava fields extend below the breach. In some cases the central crater and the breach in the ramparts have been obscured by later scoria, but normally the crater and the horse-shoe-shaped cone are well preserved. It seems probable that each centre was the scene of simultaneous effusive and pyroclastic activity, lava flowing from the crater at the same time as bursts of cinder, scoria and bombs were emitted. Scoria walls would build up on all sides except where the lava flow continuously removed any superficial debris. In this way a horse-shoe-shaped cone would be built up, partly encircling the crater source of the lava. Sometimes, activity would cease at this stage, whilst at others further pyroclastic activity after lava had ceased to flow would disguise the actual breach through which the lava flowed without substantially altering the horse-shoe like plan of the cone. In hand specimen, the lavas from these mixed centres seemed more basaltic than those from the centres which were entirely effusive.

(4) *Centres from which all the erupted material has been effusive.* The Stony Hill and the 1961 eruptive centres are characterized by thick flows of blocky lava; pyroclastic debris is negligible.

2·3·1. *Explosion craters*

The Ponds are three, roughly circular, explosion craters situated on the north-east of the island on the edge of the Base above Rookery Point. They lie on a line radiating from the Peak and are named Top, Middle and Bottom Pond in order of height. The Top Pond is fed by a stream flowing off the Peak, and drains via a series of waterfalls into the Middle Pond, which has no surface outlet. The Bottom Pond is completely enclosed. The largest of the three, Middle Pond, is approximately 600 yards from rim to rim; the lake is nearly 400 ft. below the rim, just over 250 yards in diameter, but only a few feet deep. The sides dip inwards at an average angle of 37° but in some places near the bottom this dip increases to nearly 80°.

Exposures are poor owing to thick vegetation and soil cover, but lava flows belonging to the main sequence are exposed in the north and east crater walls of Middle Pond near the rim, in the stream connecting the Top and Middle Ponds (349) and in the stream feeding the Top Pond. A small, near-vertical outcrop of red cindery agglomerate occurs near the top of the southern crater wall of Middle Pond.

Unlike the Top and Middle Ponds, the Bottom Pond has a small pebble beach which is particularly well developed on the north side (figure 34, plate 21). Although there are a few lava boulders on this beach, there are no exposures of solid lava above, the only rocks exposed being red and black cindery tuffs and agglomerates at the base of the east and north crater walls.

The few exposures available indicate that the Ponds have been excavated in the seawardly inclined lavas of the main sequence and are not constructional features. The only material derived from the Ponds themselves is fragmental debris which now forms insignificant rims around each crater, the crater lips being almost continuous with the surrounding surfaces. These explosion craters lie on a radial line from the summit, which also bisects a small cinder centre 600 yards south-west of Top Pond. The cliff section below the Ponds does not expose any significant intrusive feature along this line. Although separate vents at depth, these craters are funnel-shaped for the upper few hundred feet so that their rims coalesce. The V-shaped outlet of Top Pond is not a subsequent erosional feature, but is due to this crater overlap (figure 33, plate 21).

2·3·2. *Scoria Mounds*

Fourteen pyroclastic centres are listed under this heading. In none of these does it appear that lava was a significant feature, although cliff retreat and sub-aerial erosion may, in some cases, have removed any associated lava fields. These centres are described in a geographic sequence anticlockwise from a line drawn northwards from the summit.

Blackenole. This pyroclastic complex lies on the northern slope of the Peak, between Caves and First Lagoon Gulch and extends from 3500 ft. to 5000 ft. The surface of the Peak in this area is inclined at about 18° and the Blackenole centre, which is about 1 mile long, does not rise more than 250 ft. above the general level of this inclined surface.

Three eruptive centres have been identified within the complex. In this description, the central largest cone will be called Blackenole, whilst the other two will be referred to as the southern and the eastern vents respectively. The most pronounced feature of the cones is their marked elongation in the down slope direction. In plan, the secondary cones of the Base tend to be circular, whilst those of the flank of the Peak are markedly ovate, Blackenole being an excellent example. In common with most of the cinder centres above 3000 ft. Blackenole is well exposed being only partially covered with vegetation.

The first activity in this complex was ejection of red ash, cinder and scoria from the southern vent. This material extends from 5000 down to 3000 ft. and throughout is inclined parallel to the underlying surface. Good exposures can be seen above the west bank of Caves Gulch where erosion has produced a remarkable castellated topography in the consolidated red pyroclastic material. It would appear that the eastern centre was then formed; this is a circular cone of red cinder some 400 yards in diameter and rising to a height of just over 100 ft.

Blackenole itself is the youngest centre of the trio. Its crater is well preserved and the ejected material, which has a radial inclination, covers the scoria and ash from the other two vents. On the northern, down-slope side, the whole complex has been dissected by river erosion. Excellent exposures are to be found in the upper reaches of Plantation and Caves Gulch.

Nellie's Hump is a semicircular cinder mound $\frac{3}{4}$ mile in diameter lying between Hottentot and Wash Gulches on the north-east margin of the Base. The Main Cliffs mark the seaward margin of this centre and it is evident that virtually half has been removed by cliff erosion. As the name implies, the remaining portion forms a broad hump of elevated ground with no outstanding surface features (see figure 36, plate 21). Most of Nellie's Hump is covered with vegetation. The pyroclastic nature of the hill is, however, disclosed where narrow, steep-sided gullies cut into the north-east flank, and also in exposures high on the Main Cliffs between Little Sandy and Big Sandy Gulch. There is no definite evidence of a crater, although a semicircular depression at the head of Little Sandy Gulch could be the remnant of such a structure.

Stone Castles lie about 4300 ft. up on the western side of the Peak and form two ridges, one on each side of Spring Gulch. These ridges are capped with thick deposits of red scoria that have been eroded into prominent crags and pinnacles. The original form and extent of the scoria mound cannot be determined as the area has been deeply dissected, but the original centre of eruption is probably cut by Spring Gulch. The scoria deposits fan out downslope so that though the feature is $\frac{1}{2}$ mile wide at the Stone Castles, it is double this width $\frac{1}{2}$ mile downhill. Fine scoria and ash are still 200 ft. thick on the ridge south of East Molly Gulch, $\frac{1}{2}$ mile WSW from the probable centre of eruption. The whole area of the Base between Spring Gulch and Wash Gulch has been thickly covered with scoria and ash and is now finely dissected by narrow V-shaped valleys. The angle of deposition of the scoria is very variable; near the apparent centre of eruption the scoria horizons appear almost horizontal, whilst at the seaward margin of the mound the scoria is inclined westward at as much as 34°. Examination of the area for a possible conduit was unsuccessful and it seems likely that it is now covered by talus. Underlying the scoria, and well exposed in Spring Gulch are lavas of the main sequence that are inclined to the west at 25°.

Burntwood is a pyroclastic centre at the southern end of the Settlement plain where this platform joins the Main Cliffs. Much of this centre has been removed by marine erosion. It seems likely that the original perforation was in the immediate vicinity of the junction between the Settlement plain and the Main Cliffs, for all the ejecta are inclined in a westerly, seaward direction. The diagrammatic cross-section, figure 7, shows the probable disposition of this centre.

Red and yellow scoria, cinder, ash and agglomerate from this centre occupy a narrow strip which extends for a distance of $1\frac{1}{2}$ miles from just south of Molly Gulch southwards to Anchorstock Point. Good exposures are to be seen in Bluff Gulch and on the inclined slopes leading from the Settlement Plain to the Base at Burntwood. Pyroclastic material is found as high as 1500 ft. above sea-level; above this, the slope steepens and the near horizontal main sequence is exposed. The smooth, inclined slopes mentioned above are at exactly the same angle as the pyroclastic debris of which they are formed.

The outer margin of this centre is masked to the north by the alluvial deposits that mantle the Settlement Plain. The apparent position can, however, be placed by a marked change in slope. The outer margin meets the coast line just south of Bluff Gulch and from here southwards to Anchorstock Point excellent exposures are displayed in towering sea cliffs. Unfortunately, these cliffs were not accessible so examination of this coastal section had to be undertaken from the sea. Immediately south of Bluff Gulch, good exposures of bedded pyroclastic material can be seen, but in the promontory $\frac{1}{2}$ mile north of Anchorstock Point, the material becomes chaotically disposed and is, in all probability, a vent agglomerate. Irregular dykes of grey trachybasalt traverse this material. In the immediate vicinity of Anchorstock Point the scoria and volcanic agglomerate exposed are again well bedded and inclined at about 15° to the west.

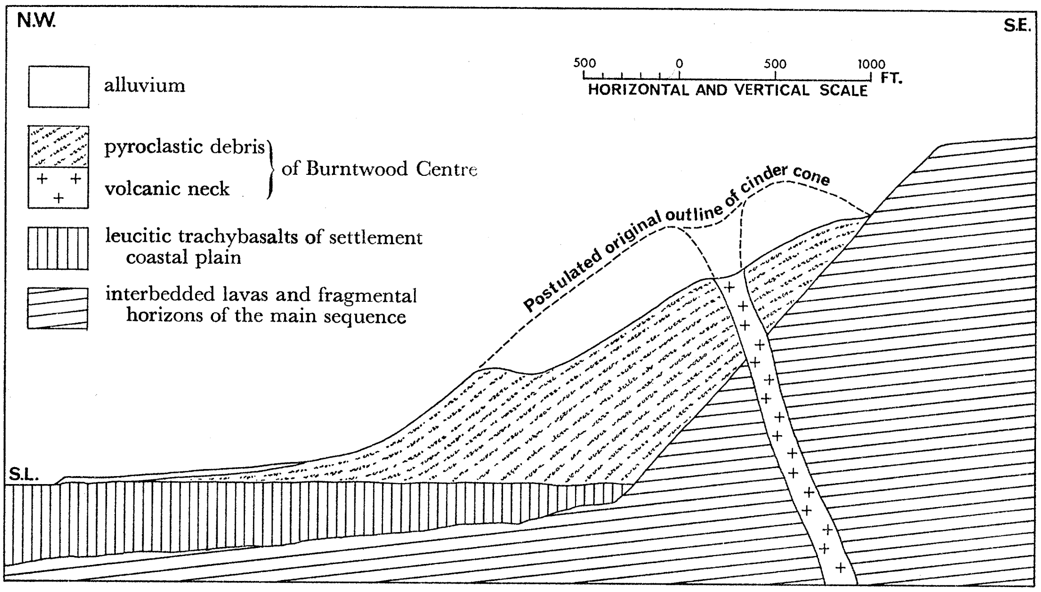

FIGURE 7. Diagrammatic cross-section through the Burntwood parasitic centre.

Perched on a narrow shelf above Anchorstock Point are two small circular hillocks which, although not examined in detail, have the appearance of being cinder cones associated with the Burntwood complex.

To the north of the main Burntwood centre, between Molly and Bluff Gulch, yellow volcanic agglomerate is exposed just west of the foot of the Main Cliffs. This material is inclined at 20° in a south-easterly direction, and would suggest that a further pyroclastic centre, now removed by erosion, existed to the north of Burntwood.

Long Ridge Pinnacles. Above Long Ridge, at about 3800 ft., are a group of conspicuous pinnacles some 30 ft. high which lie near the southern margin of a 300-yard wide natural ampitheatre drained by a tributary of Flat Gulch. These pinnacles, consisting of near-horizontally bedded red scoria, mark the crater wall of a pyroclastic centre. The scoria is of relatively uniform size, about 1 in. in diameter, the fragments are fritted or welded together to give a relatively hard though very porous rock. Occasional spindle bombs up to 1 ft. in length were found within the ash. Beneath the pinnacles, both within the ampitheatre and in the adjacent valley walls, red scoria interbedded with thin grey lavas has a radial dip of between 20° and 30°. For a distance of 400 to 500 yards downhill, red ash from this centre is at least 150 ft. thick. Upstream, the interbedded lavas and ashes of the main sequence can be seen to be inclined westwards at 20° and to underlie the mainly pyroclastic debris of the Pinnacles scoria mound.

Gipsy's Hill, named by the Expedition, lies on the south side of the Base less than ½ mile ESE of Green Hill and just above the fork in Gipsy's Gulch. It is a roughly conical mound rising about 500 ft. above the enclosing gulches, has relatively smooth upper slopes, dissected lower slopes and seems to be composed, almost entirely, of pyroclastic debris. The summit is relatively flat; there is no crater although a slight depression some 30 yards in diameter immediately north-east of the highest point may mark the position of the original vent. Good exposures, especially on the south-west flank, show that the hill is formed principally of coarse black scoria containing occasional bombs. Lavas of the main sequence exposed in Gipsy's Gulch underlie this scoria mound.

Cave Gulch Hill is a mile-long ridge of high ground that lies on the southern edge of the Base, immediately to the east of Cave Gulch. Never more than a quarter of a mile wide, this ridge is composed entirely of pyroclastic material, and consists of three overlapping cinder centres aligned in a north–south direction. The three major craters and four auxiliary rim vents all lie in a straight north–south line which, if projected, would pass through the summit of the island.

The form of the cinder cones is well preserved and exposures of reddish volcanic agglomerate can be seen in the eastern wall of the northern crater and also where Cave Gulch has eroded the western flank of the ridge. The rest of this cinder complex is covered with vegetation, and most of the craters and peripheral vents are partially infilled with swampy ponds.

To the south, this multiple cinder centre is abruptly terminated by the Main Cliffs. A volcanic neck exposed in these cliffs suggests that another cinder cone originally existed, alined with those that now lie on the Base. As mentioned on p. 468, the dyke pattern on Tristan is dominantly radial. It is suggested that the conduit along which the Cave Gulch magma ascended was a similar radial tension fracture.

About ¼ mile NNE of Cave Gulch Ridge there is a small circular hillock formed of red ash. This hillock is almost entirely vegetated and is not in line with the Cave Gulch trio. Lack of exposure prevented the detailed study of this small isolated centre.

Stony Beach Hills. Just over ⅓ mile to the east of Cave Gulch Ridge there is a small cluster of cinder cones that form a low eminence at the edge of the Base, immediately above Stony Beach Bay. The seaward part of this cinder complex has been removed by cliff-erosion. Previously, no name had been given to this cluster of hillocks; in this account they are called the Stony Beach Hills.

Immediately above the Main Cliffs are two depressions which represent the craters of these centres. In the northern crater there is a small lake, whilst the seaward edge of the southern crater has been eroded. Farther to the north, a semicircular ridge open to the west marks the site of a third centre of pyroclastic activity. A fourth, smaller but perfectly formed cone lies further to the north again and is separated from the main complex by a narrow valley. All the hills have a thick covering of vegetation.

The red cinder of which they are composed is exposed on their western flank, where landslip associated with stream erosion has removed the vegetation cover. It would appear that the small northernmost centre represents the first stage in the formation of this parasitic group. After building up a small cone, lava issued from the seaward side and now forms a narrow north–south ridge with a marked axial channel. Subsequently, the pyroclastic material from the more southerly centres covered most of this lava. It is not possible, however, to determine the relative age of these later centres of activity.

A cross-section of this cinder centre is exposed in the Main Cliffs, immediately above Stony Beach Bay. Unfortunately, these cliffs are precipitous and close examination of the section is not possible. The picture is further confused as an older pyroclastic centre immediately underlies the Stony Beach Hills complex.

Big Gulch cinder centres. Big Gulch, one of the most prominent drainage channels of the island, dissects two pyroclastic centres on its path to the sea. The higher of these two centres lies between 2000 and 3000 ft., and the lower at between 1000 and 1400 ft. just above the mouth of the Gulch. Neither has retained a typical cone form; the pyroclastic nature of the centres is revealed by exposures of yellow volcanic ash and agglomerate in the banks of Big Gulch. Remnants of the original constructional surface of these scoria mounds are readily identifiable.

The higher of these two pyroclastic centres occupies an area known locally as The Ridges. This name is derived from the steeply dissected eastern flank of the cone where erosion has cut deeply into the poorly consolidated volcanic debris forming numerous small, deep, V-shaped valleys. This cinder centre is formed of two cones which partially overlap; the western cone is almost circular and has a diameter of 750 yards, whilst the older, east centre, is oval in plan, elongated in a north-east direction and has a long axis of almost $\frac{3}{4}$ mile. The most extensive exposures are to be seen in Big Gulch on the south flank of the complex, where yellow volcanic agglomerate and ash is inclined to the south and south-east at between 10° and 20°.

On the Base, just above the Main Cliffs and bisected by Big Gulch, is a very small pyroclastic centre. This area is semicircular in plan, the seaward margin being the edge of the Main Cliffs. This eminence is about $\frac{1}{2}$ mile in diameter and rises some 150 ft. above the relatively level surface of the Base. Good exposures of yellow ash and volcanic agglomerate inclined to the east at 10° and lying on a thick grey lava flow can be seen in the northern bank of Big Gulch where it cuts through the volcanic centre.

Washout Gulch cinder centre. On the north-east quadrant of the Base in the vicinity of Washout Gulch between 2000 and 3000 ft. there is a small cinder cone that was not visited during this survey of the island. A. B. Crawford records this knoll on his map of the island, and it was seen from a helicopter on 20 March 1962. This hill has the typical form of a single cinder cone, is about 500 yards in diameter and is about 100 ft. high. Further information regarding the composition and structure of this centre is not available.

Ponds' cinder centre. 600 yards south-west of the Top Pond at a height of 2700 ft. is a small cinder cone, completely mantled with vegetation. It is circular in plan with a maximum diameter of 50 yards, and a flat, circular, boggy area 25 yards in diameter marks the position of the original crater. The lip of the crater rises only a few feet above the surrounding gently sloping surface of the Base. On the up-hill side, the lip of the crater is 20 ft. above the boggy crater floor, whilst the crater wall on the down-hill side is only

3 ft. high. The surface of the cone is inclined at between 20° and 25°, and a small pit dug in the northern lip of the crater exposed red cinder.

Big Green Hill is an almost completely vegetated cinder cone situated on the northern edge of the Base, some 2000 ft. above Big Point (figure 35, plate 21). Approximately 500 yards in diameter it rises nearly 350 ft. above the level of the Base. Its summit is marked by a crater approximately 100 yards in diameter in which there are two small circular depressions; the rim of the crater is markedly higher at its western side. The external and internal surface dips of the cone vary from 30° to 35°. A small isolated outcrop inside the crater exposes weathered red cinder. The western flank of the cone is dissected by Pigbite Gulch; here poorly cemented volcanic agglomerate consisting mainly of fragments of black scoriaceous lava is exposed.

This cinder cone overlies flows of the main sequence but between the pyroclastic material of the cone and the underlying lava there are two carbonaceous layers possibly representing fossil soil or peat deposits. This carbonaceous material was submitted to the National Physical Laboratory for radiocarbon dating, and dates of 11310 ± 168 and 10770 ± 156 years B.P. were determined for the lower and upper horizons respectively.

2·3·3. *Breached scoria cones with associated lava fields*

Thirteen parasitic centres are discussed under this heading and, and as with the scoria mounds, they will be described in geographic sequence anti-clockwise from a line drawn northwards from the summit.

Hillpiece and Burnt Hill are the most conspicuous of the breached cones and lie on the Settlement coastal strip between the Potato Patches and the Village (figures 37, 38, plate 22). When viewed from the sea it is evident that the oldest parts of the Hillpiece parasitic complex have been largely removed by marine erosion, for underlying the red pyroclastic debris of Hillpiece is yellow volcanic ash and agglomerate with an easterly, landward inclination. This material forms the two hardies off Hillpiece, is exposed near the base of the cliff section to the north of the hardies and in the northern part of Boat Harbour Bay. The Hillpiece hardies represent the most westerly exposure of this centre and at this locality the beds are inclined to the south at 15°. In the cliffs below Hillpiece their inclination can be seen to be about 10° to the south-east whilst in Boat Harbour Bay the average angle of inclination is only 5° to the south-east. From these data it is considered that the centre from which this material was erupted lay some 250 yards to the north of the seaward hardy. This is one of the few parasitic centres where the pyroclastic debris is yellow. In all other localities examined on Tristan the dominant colour is red or reddish brown. This difference in colour most probably reflects a difference in the state of the iron under varying conditions of eruption and deposition. In spite of the difference in colour the material ejected from this centre is similar in composition, though more compacted, to the reddish pyroclastic material of the Hillpiece centre itself. The best, and most accessible, exposures are in the cliffs at the northern end of Boat Harbour Bay where a sequence of interbedded yellow tuffs, lapilli and agglomerate is well exposed. At this locality there is a cyclic sequence; each unit passes upwards gradationally from a relatively coarse agglomerate through lapilli tuff to an overlying, fine-grained, bedded tuff, the cycle occupying a vertical distance of between 8 and 15 ft. The cyclic units, although repeated several times, do not extend for any great distance laterally and the tuff horizons, in particular, rarely extend for more than 100 yards before being replaced by coarser debris.

The volcanic agglomerate consists of rounded to subangular blocks of grey trachybasalt, yellow scoriaceous basalt and occasional fragments of basic glass, in parts welded together and in other places cemented by a pale-yellow tuffaceous matrix. The rock fragments, which vary in size from a few millimetres to 18 in., are apparently completely unsorted. The lapilli tuff consists of markedly angular fragments varying between 3 mm and 1 cm in size and having the same composition as the material in the volcanic agglomerate. In this case no tuffaceous cement is present and the lapilli appear to be welded together at their points of contact. The cavities between the lapilli are coated with a white powdery substance, probably a zeolite. The tuff is extremely well bedded and consists for the main part of yellow ash interbedded with less common layers formed of black volcanic ash. The grain size throughout is less than 1 mm. In places gentle cross-bedding can be seen but evidence as to whether this represents aeolian deposition in varying wind conditions or deposition in a sub-aqueous environment was not seen. Within the tuff horizons are volcanic bombs and blocks up to 1 ft. in diameter and these, on falling into the ash horizons, have contorted the beds in the immediate vicinity.

In Boat Harbour Bay there are numerous small lines of fracture presumably caused by differential compaction of the pyroclastic debris following deposition.

Hillpiece itself rises to over 700 ft. above sea-level and consists of a central group of five coalescing craters flanked on the northern side by a semicircular crater wall consisting of scoria and bombs. The crater wall dips at about 40° whilst the outer slopes of the cone and of the scoria beds beneath are inclined at between 30° and 32°. Immediately north of these craters marine erosion has cut back into the slopes of the cone and reduced the height of the crater wall. On the southern side of the craters there are minor slopes and ridges between individual centres which then open out on to the relatively flat surface of the coastal strip which, in this locality, is dotted with numerous 'hornitos' and minor cones (see figure 43, plate 24). South-east of the craters and immediately adjoining them is the second and probably contemporaneous cone of Burnt Hill which rises some 300 ft. above its surroundings and 600 ft. above sea-level. This is a relatively smooth, symmetrical dome-shaped hill whose symmetry is broken by a line of four coalescing craters extending from the south-east edge of the dome, across the summit. The crater floors are not continuous but are separated from each other by minor ramparts. The total length of the chasm created by these craters is over 300 yards and its greatest depth just over 100 ft.

As in Hillpiece, the outer slopes of this cone and the scoria beds exposed in them are inclined outwards at about 32° whilst the inner walls of the craters are inclined at 42°. Along the crest of the hill on the southern margin of the craters are two parallel ridges about 4 to 8 ft. high and 10 ft. wide and extending for 100 yards. These may represent lines of sliding or subsidence of the crater walls. Like Hillpiece, Burnt Hill consists chiefly of scoria blocks and bombs whilst some of the material exposed in the craters are fragments of ropy lava up to 2 ft. in diameter.

A further series of five small craters, each 5 to 10 yards across and about 20 yards apart, occurs at the eastern margin of Burnt Hill at the junction of Burnt Hill, Hillpiece and the coastal strip. There is no ring of ejectamenta round any of these and it is not clear if they are due to explosions or to local subsidence.

A further well-developed crater within a symmetrical scoria ring occurs west of Burnt Hill and the Hillpiece craters on the north bank of Big Sandy Gulch. Exposures in the inner walls show blocks of vesicular lava up to 1 ft. across and this cone has the usual external slope of 32° and internal slope of 42°. This appears to be the final eruptive phase of this complex.

All the cones of the Hillpiece–Burnt Hill area appear to be built almost entirely of scoriaceous material and the history of the group is complex. Undoubtedly, the yellow ash and agglomerate exposed in the sea cliffs and the Hillpiece hardies indicate the presence of an earlier eruptive centre, and Hillpiece itself was developed at a later date. Hillpiece then breached, the lava moving southwards and building up the coastal strip of the Potato Patches whilst scoria and other pyroclastic material built up a semicircular cone round the northern side. The coastal strip on either side of Hillpiece appears to have been built from lava from this centre but whether the lavas on the northern side flowed eastwards around the southern end of Hillpiece or were emitted before Hillpiece was formed is uncertain. At about the same time, or near the end of this activity, Burnt Hill must have been formed by the emission of pyroclastic debris after the Hillpiece lava had ceased to flow. Pyroclastic activity continued so that individual craters developed, separated from each other by minor walls or ramparts. The line of craters across Burnt Hill was then formed by explosive and pyroclastic activity; it seems unlikely that any lava was emitted from these as the rift is too narrow and the craters too sharp and distinct to be a normal breached cone. Later explosive activity could have excavated the small craters that exist in the valley between Burnt Hill and Hillpiece and could also have formed the symmetrical hollow cone on the north bank of Big Sandy Gulch. South-westwards from the complex the cliffs consist of lava and interlava rubble horizons but without ash or tuff horizons. However, on the northern side there are quite extensive layers of ash occurring at two horizons (p. 488). These confirm that the final stages were pyroclastic with the ash being blown mainly eastwards by the prevailing wind.

The Knobs are two small but prominent hills, separated by a minor valley, that lie at the intersection of the Peak and the Base between West Molly Gulch and First Gulch. The hills extend inland and coalesce behind the valley to form a semicircular hollow. This centre is most probably a breached cone with the breach on the seaward side having been subsequently deepened by stream erosion. The crater walls are inclined inwards at 38° and the angle of the outer slopes of the cone is 34°. There are no exposures within the crater but loosely cemented red scoria and ash are exposed where West Molly Gulch has cut into the northern flank of the cone and where First Gulch has dissected the southern flank. At both localities the beds of pyroclastic material have a radial inclination of about 30° away from the crater. Half a mile below the southern Knob, in the banks of First Gulch, 12 ft. of red ash, presumably derived from this centre, overlies alternating lava and rubble horizons of the main sequence. Behind the Knobs the surface of the Peak consists of red scoria with a seaward inclination; it is probable that this debris was derived from another parasitic, pyroclastic centre nearer the summit.

The surface of the Base below the Knobs is markedly uneven and studded with several prominent hillocks and mounds; it is probable that this area is the lava field which issued from the Knobs centre. One of the mounds, a sharp-crested ridge 30 yards long and 30 ft. high and consisting of very vesicular trachybasalt, may represent a 'lava wedge' squeezed up through the surface of the flow.

Long Ridge lies on the western side of the island between Third and Flat Gulches and extends from the junction of the Peak and the Base seawards for a distance of $\frac{1}{2}$ mile. As the name implies, the dominant feature of this centre is a long, narrow ridge of lava with a marked axial trench that extends for about 800 yards in an east–west direction and is about 100 ft. above the general level of the Base. The eruptive centre, at the uphill end of the ridge, is marked by a shallow, poorly defined crater, partially occupied by shallow pools. The crater wall, inclined inwards at 48°, is preserved only on the northern side as a steep ridge some 80 to 100 yards long that rises 40 ft. above the crater floor. Outcrops in this wall expose red scoriaceous agglomerate.

The ridge that extends seawards from the crater is formed entirely of lava derived from this centre and follows a gently sinuous course across the Base. The shallow trench, 20 to 25 yards wide and about 15 ft. deep, that divides the ridge longitudinally, creates the impression of two closely parallel ridges (see aerial photographs, plates 18 and 19). The trench and the bounding parallel ridges extend for a distance of 800 yards from the crater and within this distance descend some 500 ft., the average gradient being between 10° and 11°. Finally, the trench divides into a series of 'distributaries' which soon lose their identity in a region of hummocky ground.

It is suggested that this feature was formed by a lava stream emitted from the Long Ridge centre, the sides of the stream having been gradually built up into lava levees by the overflow and solidification of liquid lava. In the final stages the lava flowed in a narrow channel delimited by the bounding levees that had been built up to a height of 100 ft. above the surface of the Base. At the lower end of the flow the lava in the distributaries lost its fluidity and could no longer be confined to sharply defined channels. This lava channel and others identified on Tristan have been described in detail elsewhere (Baker & Harris 1963).

Frank's Hill lies on the western margin of the Base above and 1 mile to the south-east of Anchorstock Point and consists of a cinder cone with an associated lava field on its seaward side. The cinder cone is circular in plan with a diameter of 250 yards. A large crater occupies the centre so that the constructional part of the cone is restricted to a narrow ring of pyroclastic debris that rises about 150 ft. above the general level of the Base. There is a marked depression in the rim on the seaward side where the crater walls are only 30 to 50 ft. high. The crater walls are steep, near vertical on the seaward side where there is a pronounced embayment. Elsewhere they are inclined inwards at about 40°. The crater has a flat, swampy floor which is lower than the surface of the Base by as much as 50 ft. For the main part, the pyroclastic debris forming this cone is red and black scoria but on the seaward side, above the embayment in the crater floor, the debris consists of large ejected blocks and bombs of vesicular lava some 4 to 6 ft. in diameter. Seawards from the cinder cone is an elongate hummocky surface that marks the extent of the lava extruded from this centre.

Volcanic activity probably commenced with an explosive phase that formed the cinder cone whilst the lava subsequently extruded, breached the seaward wall, transporting any pyroclastic debris that fell in the breach. In the final stages the activity must have been extremely explosive, lowering the floor of the crater well below the surface of the Base whilst the blocks ejected partially filled the breach to a height of 30 to 50 ft. and added to the scoria cone elsewhere.

Mate's Hill is a small but typical breached cone that lies on the south-west of the Base at between 2400 and 2500 ft. and is bounded to the north and south by the main tributaries of Flat Gulch. The scoria mound, which is about 300 yards in diameter and 100 ft. high, is breached on the south-western seaward side. The cinder cone is formed of red basaltic scoria whilst a tract of hummocky, densely vegetated ground marks the extent of the lava field issued from this centre.

Green Hill is a prominent breached cone just below the south-west junction of the slopes of the Peak and the Base. The cone is circular, some 550 yards in diameter and rises on the uphill side about 200 ft. above the surrounding surface. It is about 600 ft. above this surface on the seaward side. The crater, which contains two remnants of a former crater lake, is 100 yards in diameter and the crater walls are between 100 and 150 ft. high. Along the rim of the crater large blocks of red, vesicular, basic lava are exposed whilst on the southern, outer slopes 40 ft. of fine ash coarsening downwards and resting on scoria are exposed in a recent landslip. This sequence is inclined southwards away from the crater at 30°. Similar pyroclastic debris is exposed on the eastern flank, which has been partly dissected by stream erosion.

Below the breach in the crater wall there is an elongate depression containing a central lava ridge 40 ft. high and 100 ft. in length, which was probably formed in the closing stages when the lava had become more viscous. Farther from the crater, the depression constricts into a well-defined lava channel which subsequently divides into two before losing its identity. An area extending for about 1000 yards on the seaward side of Green Hill appears to have been formed of fluid lava derived from this centre.

Hackel Hill is a breached cone on the Seal Bay coastal strip on the south-west side of the island. This centre, and particularly the lavas that issued from it and formed the Seal Bay Plateau, is described in § 2·4·2, p. 490.

Round Hill lies on the Base almost due south of the Peak at between 2400 and 2850 ft. Despite the fact that it is almost completely covered with vegetation, it retains a virtually perfect shape and forms the seaward margin of a level expanse of ground known as Soggy Plain. Although lying between 2400 and 2850 ft., the cone never rises more than 170 ft. above the gently sloping surface of the Base. The original, almost circular, cinder cone is about 750 yards in diameter and has been breached on the seaward side. A narrow tongue of hummocky ground, slightly raised above the surrounding surface, indicates the extent of the single lava flow of vesicular trachybasalt that issued from this centre. The outer slopes of the cone are completely vegetated and have an average gradient of 24° whilst the rim of the crater appears to have been slightly rounded by subsequent erosion. Isolated outcrops in the northern and south-eastern walls of the crater expose red ash and scoria. The small, almost perfectly conical hill on the south-western rim of the main cone is thought, on morphological grounds alone, to be a separate centre of pyroclastic activity.

The-Hill-with-a-hole-in, and a similar breached cinder cone nearby form part of the cluster of parasitic centres of the Stony Hill Plateau. They are described in § 2·3·5, pp. 481 to 486.

Blineye, at the extreme south of the island, is a large breached cone which is particularly instructive as marine erosion has removed the eastern part of the centre. The cliffs above the southern part of Stony Beach expose an excellent north–south section through this parasitic volcano. Like the Burnt Wood scoria mound (p. 471) the initial vent of the Blineye centre must have been near the foot of the Main Cliffs as pyroclastic debris from this centre banks up against these cliffs to the north.

Blineye differs from most of the other breached cones in that its crater rim is markedly elongate, over 500 yards in a north–south, downslope direction, 300 yards across from east to west, and that the breach, on the SSW side, is at an angle of about 30° to the longer north–south axis. The southern rim of the crater is relatively flat-topped with a small axial depression. It seems likely that the southern rim of the main crater was extended by a second peripheral vent causing the breach to open farther to the west. The crater floor is roughly circular, about 80 yards in diameter and is bounded, with the exception of the breach, by walls some 200 ft. high and inclined inwards at 34°. On the northern side the crater wall can be divided into a lower and an upper slope. The lower, inner wall is about 200 ft. high, the concave upper slopes extending another 150 ft. higher to the crater rim. Beyond this crater rim there is an arcuate strip inclined outwards for a distance of about 20 to 30 yards before it meets the slopes of the Main Cliffs. The slopes of the Main Cliffs in this area are formed of ash which is 200 ft. thick in places and appears to have been derived from the Stony Beach Hills at the top of the cliffs.

Excellent exposures are to be seen in the cliff section to the east of Blineye and in the banks of Cave Gulch to the west. In the eastern cliff face, which is 300 yards long and 100 ft. high, a feeder of this centre is exposed with scoriaceous beds dipping away on either side. This neck is 75 ft. wide and consists of pale-grey leucitic trachybasalt (194) (analysis, table 6 facing p. 520; petrography, p. 496) having a well-developed vertical columnar jointing. Plutonic xenoliths are present within the finer grained trachybasalt and are particularly abundant on the western crater rim. For a distance of about 20 yards around the neck the scoria dips inwards, then going outwards the attitude of these fragmental horizons flattens until at the limits of the outcrop the beds have an outward dip of 21° on the northern limb and 32° on the southern. When projected, this feeder vent does not coincide with the main crater and probably fed a secondary peripheral vent that has been removed by erosion. Cave Gulch cuts into the western flank of Blineye and exposes basaltic scoria dipping outwards from the crater at about 30°.

The lava which issued from this centre has been covered by the loose detritus in the bed of Cave Gulch and by the younger lava of the Stony Hill centre.

Red Hill sits on the edge of the Base immediately above the southern end of Sandy Point. It is a well formed, near circular, breached cinder cone with a diameter of just over half a mile and rising some 300 ft. above the Base. The outer slope on the landward side is inclined at 25° whilst the seaward slope, which is much more gently inclined, is less well defined. The crater is marked by a semicircular depression open to the east where the wall of the cone has been breached. On the western rim of the crater three small depressions, now completely infilled with swampy lakes, mark the possible site of peripheral vents. Although the cone is virtually covered with vegetation, exposures in the narrow gullies that drain the northern flank reveal bedded yellow volcanic agglomerate that is inclined to the north at about 20°; this is the angle of the overlying surface. Inside the crater, an isolated outcrop of red cinder in the north wall confirms the pyroclastic origin of the centre.

Although the east wall of the cone has been breached, there is no topographic evidence that any lava was extruded from this centre. The narrow area between the cinder cone and the Main Cliffs, where a lava flow might be expected, has been deeply incised and is covered with dense vegetation. It is probable that any lava extruded would have been deeply dissected and mainly removed by subsequent erosion.

On the north side of the island at the junction of the Peak and the Base and about 1 mile south of Big Green Hill, there is a small but well-preserved breached cinder cone; this is probably the *Little Green Hill* of the islanders. The cinder cone is circular in plan with a diameter of 250 yards, rises some 75 ft. above the level of the Base and the crater is 100 yards wide at the rim. The cone has been breached on the northern seaward side and the hummocky lava field that extends for a quarter of mile to the north is divided by an axial channel. The cone and its associated lava field are almost entirely covered with dense vegetation. Isolated exposures on the western flank of the cone reveal red scoria inclined at about 30° away from the crater.

2·3·4. *The age of the parasitic scoria mounds and breached cinder cones*

The discovery and subsequent dating of the soil horizons under Big Green Hill gives a datum by which the relative ages of other scoria mounds and cinder cones can be estimated. This estimation is based solely on the extent to which the cinder cones have been affected by sub-aerial erosion compared to Big Green Hill. Only the parasitic, pyroclastic centres of the Base and the coastal strips are considered because centres on the slopes of the Peak lie in a markedly different erosional environment.

Pyroclastic debris from Big Green Hill immediately overlies the upper soil horizon which has been dated by radiocarbon methods as being 10770 ± 156 years B.P. It is suggested that an age of 10000 years for Big Green Hill itself would be relatively accurate. The following centres have been less affected by sub-aerial erosion than Big Green Hill and are considered to be younger: Hillpiece and Burnt Hill, Frank's Hill, Hackel Hill, Kipuka Hill, Hill-with-a-hole-in and the Stony Beach Hills.

In a similar erosional state to Big Green Hill and probably of about the same order of age are: Mate's Hill, Green Hill, Round Hill and Little Green Hill.

The following centres are more deeply eroded and are in all probability older than 10000 years: Nellie's Hump, Stone Castles, The Knobs, Red Hill and the Big Gulch cinder centres.

2·3·5. *Effusive centres*

Only two of the parasitic centres belong to this group: Stony Hill on the south side of the island and the 1961 centre near the Settlement. Stony Hill and the associated cinder cones that lie within its lava field will be described below in more detail than the other parasitic centres for it is directly comparable with the 1961 centre that is the subject of Part III of this report. In particular, the petrography of the Stony Hill and associated lavas will be described in detail as the rocks are virtually identical with those of the 1961 centre.

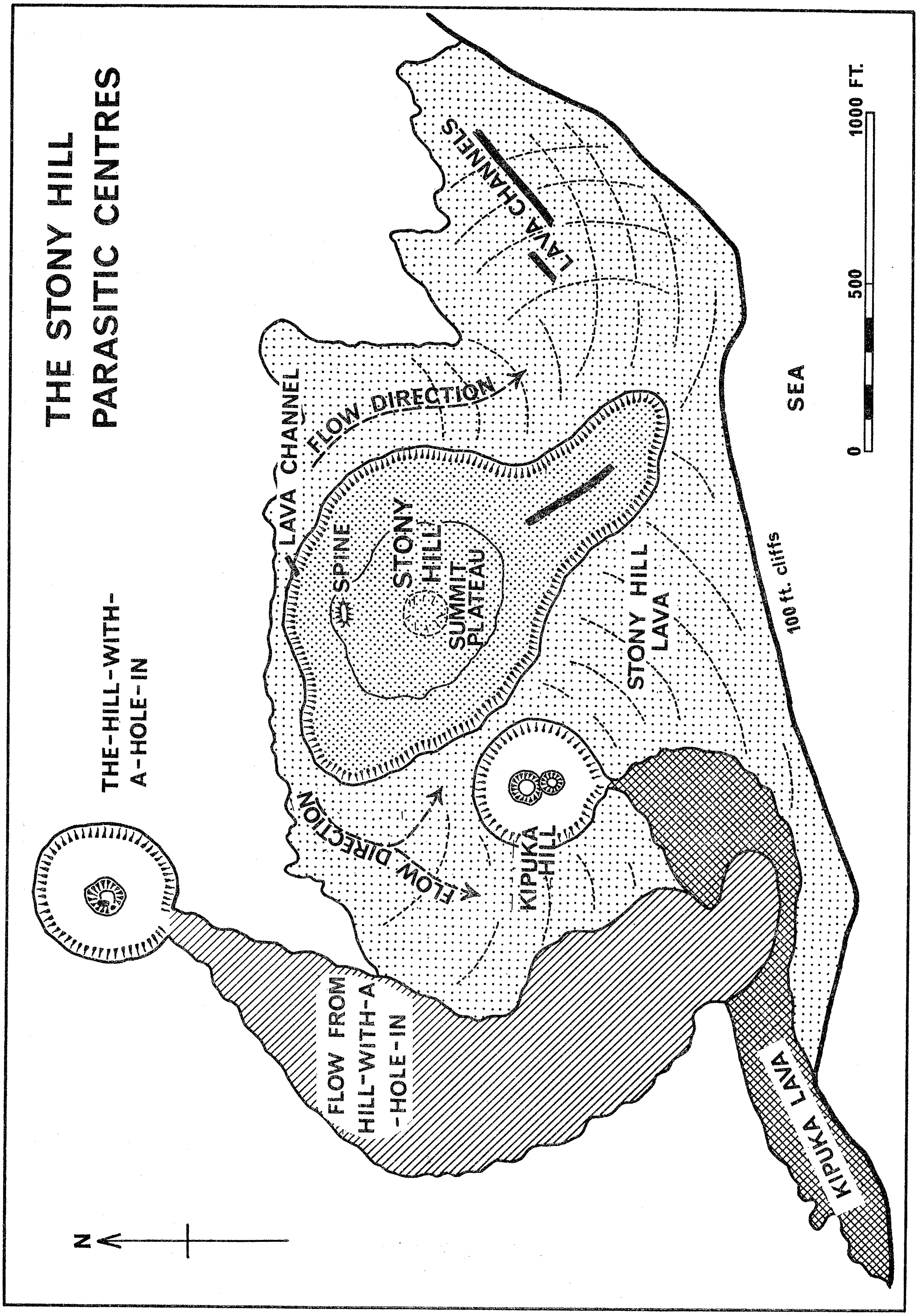

FIGURE 8. The Stony Hill parasitic centres.

The Stony Hill Group of parasitic centres lies at the eastern end of the Stony Hill Plateau which is an area of low-lying ground on the south side of the island analogous to the Settlement plain. The group consists of an effusive centre, Stony Hill, and two nearby breached cinder cones, *The-Hill-with-a-hole-in* and an unnamed cone immediately to the west of Stony Hill that will be called *Kipuka Hill* in this report. The position of the three centres and their associated lava fields is depicted in figure 8, and figures 39, 40 and 41, plate 23.

The Stony Hill volcano shows very little trace of weathering; delicate structures in the lava are well preserved, there is no soil covering and the only vegetation is in the form of a few clumps of grass and occasional *Phylica* trees. The surface consists of blocks of lava precariously balanced one upon the other as on the lava flow from the new parasitic volcano (p. 549). The absence of erosion, lack of vegetation and the nature of the lava surface indicate that the Stony Hill eruption was probably only 200 to 300 years ago. Kipuka Hill and The-Hill-with-a-hole-in cinder cones are more thickly vegetated; this does not necessarily mean that there has been any considerable lapse of time between eruptions from the three centres since vegetation has not been established to any extent on the blocky lava flows associated with these centres. The single flow from Kipuka Hill is partially covered by the seaward end of The-Hill-with-a-hole-in lava which, in turn, has acted as a barrier to the eastern flow from Stony Hill (see figure 8). Therefore, the sequence of eruption, in order of decreasing age, is Kipuka Hill, The-Hill-with-a-hole-in and lastly Stony Hill.

Kipuka Hill, the lower and broader of the two cinder cones, attains a height of about 250 ft. and possesses two summit craters which are virtually contiguous; the northern crater is slightly the larger of the two. The upper part of the cone was breached on the southern seaward side emitting an extensive *aa* lava flow. The eastern part of this flow was subsequently covered by lava from the Stony Hill centre.

In the hand specimen the Kipuka Hill lava is a dark, glassy, highly vesicular rock with occasional phenocrysts of feldspar. Under the microscope it can be seen to be a trachyandesite consisting of phenocrysts of plagioclase, pyroxene, amphibole and ore set in a dense, dark brown, glassy mesostasis.

Phenocrysts of plagioclase up to 1·5 mm long are rare; they contain a large unzoned core (An_{62}) surrounded in turn by a corroded glassy zone and a zoned border. Plagioclase microphenocrysts range in size from 0·4 mm to about 0·05 mm. These microphenocrysts have a relatively large unzoned core (*ca.* An_{60}) with a border zoning down to approximately An_{40}. Microphenocrysts of greenish-brown pyroxene strongly pleochroic from pale-greenish brown (X) to a pale-brown (Z) with marked hourglass zoning are common. The extinction angle $\gamma \wedge c$ is approximately 38°. The mineral is probably a titaniferous augite.

Phenocrysts of amphibole up to 1·0 mm in size with a pleochroic formula of X = pale-yellow, Y = yellow-brown, Z = deep golden-brown are rare. The extinction angle $\gamma \wedge c$ is 12° and the crystals examined showed a trace of resorption in the form of a thin but solid opaque rim of magnetite.

The groundmass consists of aegirine, plagioclase microlites and ore, set in a dark, glassy mesostasis.

The-Hill-with-a-hole-in lies approximately 100 yards north of the edge of Stony Hill. This scoria cone is about 300 ft. high, 150 yards in diameter at the base and 30 yards at the summit; its flanks have an inclination of approximately 35°. The cone has a well-defined summit crater 25 ft. deep whose walls are formed of a loose scree of vesicular to spongy and often reddish lava fragments and dip inwards at between 45° and 38°. The highest part of the crater rim is to the west and the lowest on the south-west immediately above the lava flow. Two vents are situated within the crater. The northern one is at the lowest point of the crater floor, measures approximately 3 yards long by 1 yard, is elongated in a north-westerly direction and is 20 ft. deep. The southern vent is just below the crater rim on the south-west side. Roughly circular, this orifice is about 4 ft. wide and its floor could not be detected; it is certainly much deeper than the northern vent.

This centre does not have an open breach; the single lava that is associated with it appears to issue from the base of the cone. It is possible that only the base of the cone was breached but more likely that following the effusive phase the cinder cone was enlarged by subsequent explosive activity.

The lava forms a very prominent feature extending in a seaward direction for about 700 yards (see figure 8 and figure 41, plate 23), and the flanks of the flow form steep, blocky slopes about 20 ft. high.

In the hand specimen the lava from this centre is pale-grey, generally compact and aphanitic with very occasional feldspar phenocrysts about 1 mm in diameter. In thin section, it is weakly porphyritic with phenocrysts of plagioclase, pyroxene, amphibole and ore set in a microcrystalline to glassy groundmass. Plagioclase phenocrysts are by far the most abundant and their subparallel orientation gives a trachytic texture to the rock. They have a large core which varies from An_{55} to An_{60} and a rim of andesine which reaches approximately An_{37} at the margin. Occasional large phenocrysts of plagioclase, up to 1·5 mm long, have a rather sodic core (*ca.* An_{40}) surrounded by a strongly corroded glassy zone at the junction with the enveloping border.

Microphenocrysts of pyroxene are common. They usually have a prismatic habit and are up to 0·4 mm long. Pleochroism varies from pale-green (X) to pale-brown (Z) in most cases, but some pyroxenes have a non-pleochroic bright-green core and a brownish rim. The core is probably aegirine-augite and the rim titanaugite. The pleochroic varieties have a $2V$ of approximately 62° (positive).

Amphibole phenocrysts are rare, pleochroic in varying tones of brown and are probably basaltic hornblende.

The groundmass is composed of plagioclase and pyroxene microlites in a mesostasis of alkali feldspar and ore together with varying amounts of glass. The rock is a trachy-andesite.

The Stony Hill parasitic volcano is an effusive centre consisting of a blocky central tholoid surrounded by low-lying rubbly *aa* and block lava. The tholoid which is approximately 300 yards in maximum diameter is distended in a south-easterly direction (see figure 8). Its flanks are everywhere very steep and are composed of large blocks of lava, often precariously balanced. The presence of a deep channel along the distension of the tholoid suggests that the bulge owes its formation to the migration of lava from the centre in a south-easterly direction. The summit of the tholoid is roughly circular with a diameter of about 150 yards and consists of a featureless plateau surrounded by a very irregular and ill-defined rim. The surface of the plateau, which is formed of large blocks of pale-grey lava, is traversed by numerous irregular chasms and crevasses. There is no obvious crater or vents although there is a slight depression at the centre of the plateau where a small group of *Phylica* and ferns are clustered. Perched on the rim, huge craggy pinnacles of lava encompass the central plateau amd overlook the lava field. The highest point of Stony Hill is the summit of a prominent feature, probably a spine, situated on the northern rim. About 15 yards in diameter at the base and rising to a height of about 40 ft. above the plateau, it tapers upwards, possesses a well-defined vertical jointing, and is composed of the same grey lava as the remainder of Stony Hill. Along the crest of the bulge to the south-east is a very well-preserved lava channel 25 ft. deep tapering from a width of about 20 ft. at the top to 4 ft. at its floor. This and other lava channels are discussed elsewhere (Baker & Harris 1963).

The nucleus of Stony Hill, represented by the tholoid, is completely surrounded by lava flows which would appear to have moved initially along the axis of the south-eastern lobe prior to diverging both to the north-east and to the south-west. The lava reaches the coast along a front about 1400 yards wide, and it is probable that its extent has been considerably reduced by vigorous marine erosion.

The cliffs at the seaward margin of the lava show two distinct flows each about 30 ft. thick and separated by a rubbly bed about 6 ft. thick. The lower lava is highly vesicular, the cavities being elongated horizontally in the direction of flow. The upper flow is generally non-vesicular but has a marked banded appearance accentuated on weathered surfaces. This banding is on a very small scale, each unit being about 5 mm thick and often having a slightly different colour to the layers on either side; this structure is probably due to laminar flow.

Although some of the lava undoubtedly travelled along the route demarcated by the south-eastern lobe of the tholoid, the remainder appears to have escaped from a point on the northern side below the present position of the spine. This is supported by the distribution of the lava and also by traces of a short lava channel which are preserved at this locality (see figure 8). The lava seems to have moved both eastward and westward from this point, the possibility of any significant expansion to the north being precluded by the slope of the terrain. The eastern flow skirted the edge of the tholoid, before swinging south-eastwards and extending laterally. The western flow also kept close to the edge of the tholoid before turning southwards to surround Kipuka Hill on its way to the sea.

In the hand specimen the Stony Hill lava is a medium grey, finely porphyritic rock with occasional phenocrysts of feldspar and elongate hornblende up to about 3 mm in length, and closely resembles the lava from the new parasitic volcano (see pp. 551 to 553). A suggestion of banding has been imparted to the rock in places by the alternation of aphanitic layers with horizons in which very small feldspar phenocrysts are concentrated.

Under the microscope the lava exhibits hyalopilitic and slightly trachytic texture showing subparallel phenocrysts of plagioclase, pyroxene and a strongly coloured amphibole in a microcrystalline to glassy groundmass. Plagioclase phenocrysts up to 1·5 mm diameter have large unzoned cores of labradorite (An_{60}) and a finely zoned border ranging to acid andesine (An_{35}) at the rim. Microphenocrysts, averaging about 0·4 mm in diameter, show approximately the same range in composition as the larger crystals. Most of the plagioclases are free of inclusions and alteration products; only the larger phenocrysts show vitreous spongy areas which sometimes occupy a large part of the centre of the core and in other cases, an intermediate zone between core and rim. Pyroxene phenocrysts show a prismatic habit and are noticeably coloured. They display well-defined zoning, the different zones having different pleochroic formulae. The core is faintly pleochroic in varying intensities of a pale-green ($X > Y > Z$). This is surrounded by a wide zone with the pleochroic formula: X = pale-purplish brown; Y = pale-purplish green; Z = pale-green; the absorption is $X > Y > Z$. In the very narrow outer rim X = olive-green; Y = pale-green; Z = colourless. Absorption is stronger than in the previous cases. A possible interpretation of these zones is that the core is a soda augite, the wide border a titaniferous soda augite and the thin outermost rim a titaniferous aegirine. The $2V$ of the core varies between 59° and 62°, and hourglass zoning is common (Yagi 1953).

Amphibole occurs as phenocrysts up to 1 mm in diameter and invariably shows some degree of resorption; it is sometimes completely replaced by ore. Two varieties were recognized: the more abundant type has the pleochroic formula X = pale straw-yellow; Y = yellowish-brown; Z = deep greenish-brown, the absorption being $Z > Y > X$. This is optically negative with a $2V$ varying from 67° to 70° and a small extinction angle ($\gamma \wedge c$ 2–3°). The less common variety has the following pleochroic formula: X = pale straw-yellow; Y = yellowish-brown; Z = deep reddish-brown and the extinction angle appears to be somewhat larger, $\gamma \wedge c$ up to 10°. It is likely that the minerals are varieties of basaltic hornblende.

The hyalopilitic groundmass consists of a network of small plagioclase laths (*ca.* An_{35}), aegirine microlites and ore in a turbid mass of alkali feldspar and abundant brownish glass. Analyses of the specimens from the tholoid and lava flow of this centre (230, 232) are given in table 6.

Like the lava from the 1961 parasitic volcano, which it strongly resembles in chemical and petrographic character, the Stony Hill lava is a trachyandesite. Very minor differences exist between the lavas from these two most recent centres. These are that: the cores of the plagioclase phenocrysts are slightly more calcic in the new lava (An_{68}) as compared with those in the Stony Hill lava (An_{60}); the groundmass plagioclase shows the same difference (1961 lava An_{40}, Stony Hill lava An_{35}); there are no aegirine phenocrysts or xenocrysts in the Stony Hill material; the Stony Hill lava has a higher percentage of amphibole phenocrysts; the amphibole of the 1961 lava is a reddish-brown variety, whereas that of Stony Hill is predominantly greenish-brown in the direction of maximum absorption.

2·4. *Coastal strips*

There are four areas of low-lying ground between the foot of the Main Cliffs and the sea: The Settlement Plain on the north-west, Seal Bay and Stony Hill Plateau on the south side, and Sandy Point at the eastern extremity of the island. The first three come under the general classification of coastal strips whilst Sandy Point is part of an older, mainly pyroclastic, parasitic centre.

The coastal strips form some of the most interesting features of the island, since at first sight they appear to be down-faulted portions of the Base, backed by enormous fault scarps. However, as mentioned earlier, it is certain that the coastal strips were formed in place by lava erupted from local parasitic centres after the Main Cliffs had been formed by marine erosion.

Along almost their entire length the coastal strips are fringed by low sea cliffs and in these cliffs it can be seen that the strips are formed mainly of lava but with pyroclastic material dominant in some sections. In only a few cases is there any thickness of alluvium above the volcanic rocks as exposed in the cliff section.

Inland, away from the sea cliffs, the surface of the coastal strips rises gently to the foot of the Main Cliffs. In nearly every case this slope is due to, or has been modified by, the deposition of alluvium from the streams that cross the strips. So, in effect, the strips are covered by coalescing fans forming a piedmont alluvial plain. Gulches excavated in the surface of this plain are almost entirely in alluvium, which is often over 50 ft. thick. Solid lava is exposed in the gulches only where they descend the sea-cliffs or the Main Cliffs behind the strips. Consequently, the geology of these strips can only be studied in the fringing sea-cliffs and the parasitic centres lying on them.

2·4·1. *The Settlement Plain*

This continuous alluvial plain is 5 miles long and extends from the eastern edge of the new lava to Burntwood (see figure 42, plate 24). Hillpiece and the adjacent cinder centres divide the plain topographically. The southern portion is a roughly rectangular tract of ground with a gentle seaward slope, some 3 miles in length but only $\frac{3}{4}$ mile wide at the maximum. North of Hillpiece the strip narrows to 250 yards for about $\frac{1}{2}$ mile and then widens and swings eastwards, following the line of the Main Cliffs. The Settlement stands on this eastern portion of the strip. The new volcano is at the extreme northern end, adding to its length by some 500 yards and increasing its area by about 20 acres.

The lavas building the coastal strip are leucitic trachybasalts with minor rubble or fragmental horizons. They appear to have been derived from Hillpiece, or from parasitic centres in its vicinity. The complete succession is exposed only in the sea-cliffs, and these are now described from north to south.

At the northern end of the Settlement Plain, at the junction with the new lava field, the cliff exposures show many unusual features. The lowermost lava, now exposed in the foreshore, has the form of enormous finger- or bolster-like lobes elongated northwards and projecting out into the sea. These lobes have a relatively uniform direction and are either horizontal or have a gentle seaward inclination. Occasionally they can be seen to divide or to unite and in places pass under or over neighbouring lobes. In cross-section they are more often oval than circular and usually measure between 2 and 8 ft. in width and between 1 and 3 ft. in height, and can be up to 40 yards in length. An average size would be 4 ft. wide by 2 ft. thick, and 25 yards in length. In general, the bases of the lobes conform roughly to the hollows formed by the tops of the underlying structures but cavities between individual lobes are frequent. The surface of each lobe is chilled and glassy and displays fine, rope-like markings (*filament pahoehoe*).

The appearance of the lava itself varies markedly within the individual lobe. The outermost 2 to 3 in. are chilled to a glass which often contains vesicles up to 1 cm across usually occurring in concentric zones. Inwards, towards the centre of the lobe, the rock becomes increasingly crystalline until in the centre of the thicker lobes whitish patches about 3 to 4 mm in diameter and resembling spherulites have developed. This patchy appearance does not occur in the thinner lobes but only in those which are over 3 ft. in diameter.

These 'spherulitic' markings are accentuated by weathering, and the rocks in which they occur are generally soft and friable in contrast to the chilled margins which are remarkably fresh. These white patches are due to the development of 'blebs' of interstitial leucite, and leucite-bearing lavas with this characteristic spotty appearance are encountered throughout the length of the Settlement Coastal Plain.

It would seem that these bolster-like structures are entrail lavas characteristic of basaltic pahoehoe material advancing by the extrusion of lobes or toe-like protuberances and with many superficial resemblances to pillow lavas (figure 44, plate 24).

Exposed in the 60 ft. high sea cliffs north of the Settlement and apparently overlying the bolster lava described above is a flow of leucitic trachybasalt characterized by the white 'spherulitic' patches of interstitial leucite. Here, this lava, which is some 50 ft. thick, has well-developed near-horizontal lamellar flow planes, which give way in places to vertical structures. These vertical structures are marked at their margins by the upward swing of the lamellar flow planes and their centres are usually filled with rubbly material. These 'chimneys' were probably caused by gas, collecting at the base of the flow, forcing its way upwards through the overlying plastic lava. The rubble mounds near the potato patches (p. 489) are thought to be the surface expression of such a mechanism, although no similar mound has been identified in the Settlement area.

Table 2

description	thickness (ft.)
alluvium	2–3
lenticular lava flow	0–8
thin intermittent layer of alluvium	0–3
yellow ash passing downwards into red scoria with abundant bombs	40
upper lava	20
reddish rubble horizon with bombs and blocks up to 3 ft. in diameter	20–30
lower columnar jointed lava	65

Going westwards, the cliffs become slightly higher and at Herald Point a second, younger lava overlies that just described. In this locality a 2 to 3 ft. band of rubbly debris cemented by thin driblets of ropy lava separates the two horizons of solid lava. Both lavas are similar in hand specimen, having a marked spherulitic appearance. Towards Hottentot Gulch the upper flow thickens to about 30 ft. South of Hottentot Gulch in the direction of Hillpiece, the lower flow gradually thickens and here displays well-developed columnar jointing. The upper flow also appears to thicken in this direction but the increase in the height of the cliffs is mainly due to the gradually increasing over-burden of red ash and scoria. In the cliff section immediately north of Hillpiece the sequence was measured as shown in table 2.

Beneath Hillpiece and extending to the south side of Boat Harbour Bay the cliff section exposes the pyroclastic material of the Hillpiece parasitic centre that has already been described (p. 475).

Moving south-east along the cliffs away from Hillpiece, the sequence of lavas and the intervening rubble horizons, although too irregular and impersistent to permit accurate measurement of their attitude, appear to be gently inclined southwards. The thicker horizons show well-developed columnar jointing which in places, e.g. at the Hardies, facilitates erosion by wave attack. Some of the thinner lavas have ropy bases and tops, and the rubbly inter-lava horizons often contain ropy fragments. In places the lavas can be seen to split laterally into two or more flows each separated by a rubble horizon. A good example of this can be seen about 400 yards south-east of Boat Harbour Bay where in the space of 50 yards, a 40 ft. massive, columnar jointed lava splits into three irregular flows. Farther south, a single flow increases in thickness from 6 to 40 ft. within a distance of 20 yards. Beyond this point the cliff section consists of a single 40 ft. flow of leucitic trachybasalt and this extends south-eastwards as far as Molly Gulch, where alluvial detritus masks all rock outcrop. South of Molly Gulch the rocks exposed are pyroclastic and have come from the parasitic centre of Burntwood.

Throughout the sea cliffs between Hillpiece and Molly Gulch, the lavas exposed are similar in hand specimen, having on their weathered faces the white spotted or spherulitic appearance, already described, indicating the presence of interstitial leucite. These leucite spots do not occur in the chilled margin nor are they usually found within 1 ft. of this margin. Sometimes they are alined by flow banding so that some bands are crowded with spots whilst in adjacent zones the leucite blebs are virtually absent. The spots range in size from 7·5 mm down to 1·5 mm and were seen in all the lavas of the Settlement Plain south of Hillpiece even in the columnar jointed lava.

South-east of Hillpiece and in the vicinity of the potato patches the original lava surface is still exposed. It is studded with over fifty minor peaks and ridges which rise above an otherwise level surface veneered with soil and alluvium (figure 43, plate 24). These hillocks vary in height from 4 to 55 ft. and in diameter from 10 ft. to just over 100 yards. None has a crater and all seem to be built of blocks of highly vesicular lava. Pyroclastic material, including a few spindle bombs, is often cemented by driblets of pahoehoe lava. The larger blocks, some 3 to 4 ft. in diameter, are vesicular in their outer portions but have non-vesicular interiors. In only one peak was solid lava exposed and here it formed a continuous surface some 8 ft. across.

These cones and ridges appear to be secondary structures built by the escape of fluid lava from the flows beneath. They are therefore analogous to hornitos in the position they occupy with respect to the lava field but differ in that they are formed for the main part of fragmental material and not of entrail lava. It is suggested that these cones were formed by the escape of gas through the overlying quasi-solid lava to build secondary pyroclastic mounds on its surface.

The alluvium that almost completely mantles the lavas of the Settlement coastal strip has a thickness of up to 200 to 300 ft. In the narrow gorge cut by Hottentot Gulch as it crosses the strip, this alluvial detritus is particularly well exposed. Here the detritus consists of a heterogeneous assemblage of subrounded to angular boulders varying in size from 6 in. to 8 ft., set in an angular sandy matrix. In composition the boulders represent a wide variety of the lavas found in the main sequence. The matrix is composed of identical material. Although boulders are plentiful throughout the exposures, there are occasional thin, 1 to 2 ft. horizons where arenaceous material is dominant. In these sandy layers current bedding is often displayed and some horizons show well-marked graded bedding. There is no apparent decrease in the proportion of boulders with increasing distance from the Main Cliffs across the Settlement plain.

It is clear that all the pre-1961 lavas and scoria that form the coastal strip have been derived from the vicinity of Hillpiece. This suggestion, although mainly based on field criteria, is supported by chemical data. Two lava specimens, one from the entrail lavas north of the village and another from the area of Boat Harbour Bay, together with a third specimen taken from a vesicular block at Hillpiece, are all virtually identical in their chemical composition. The original extent of the coastal strip is problematical but it is known that a secondary centre must have existed 250 yards north of The Hardies and this in turn suggests that the coastal strip was, at the time of its formation, at least twice as wide as it is at present.

2·4·2. *Seal Bay Plateau*

Extending south and south-east from Hackel Hill is a coastal strip about 1 mile long and $\frac{1}{2}$ mile wide (figure 45, plate 24). This plateau appears to consist of lavas extruded from the Hackel Hill centre. The lavas are overlain, along the north-eastern margin, by alluvium derived from the Main Cliffs. The lavas are gently inclined, their upper surfaces dipping south-east from Hackel Hill at about 4°.

In Seal Bay itself, only one lava flow is exposed; it is at least 30 to 40 ft. thick and has pronounced jointing, sometimes vertically columnar, but usually irregular. Vesicles in the lava are elongated seawards in the direction of flow and the massive, well-jointed lava displays spheroidal weathering; this passes upwards into a pronounced slaggy or rubbly top. Caves and arches are developed in the sea-cliffs.

Moving north-west from Cave Point, the cliffs become higher, due to the existence of further flows. At first, two flows separated by a rubbly horizon are encountered, this increasing to three and finally to five or six flows in the sea-cliffs immediately below Hackel Hill, at the mouth of Gipsy's Gulch. Here, the upper three or four flows are thin and irregular with intervening rubble horizons. The underlying flow is 30 ft. thick and lies on a 10 to 15 ft. rubble horizon. The lowest flow exposed has well-developed vertical columnar jointing and is 60 to 80 ft. thick. Unfortunately, the cliffs are inaccessible and it is not possible to trace the continuity or the individual flows in these localities.

The form of the breached cone of Hackel Hill confirms the origin of the plateau. This scoria cone is some 300 yards in diameter and is composed of red and black basaltic scoria with occasional small coarse-grained xenoliths. Flanking the breach on the southern seaward side, and extending for about 100 yards southwards are two ridges about 30 ft. high. Beyond the ridges the lava field which issued from this centre is studded with a series of mounds and hillocks similar in most respects to the tumuli on the lava field south of Hillpiece.

2·4·3. *Stony Hill Plateau*

This coastal strip has a more complex origin than Seal Bay Plateau, and has been much more modified by coastal erosion and by deposition of alluvium; it is described for the main part in § 2·3·5 dealing with secondary effusive centres (pp. 481 and 486).

It is considered desirable to correlate the various episodes of parasitic volcanic activity that contributed to the formation of this coastal strip. The first stage was probably the eruption of the Blineye centre. The breach of this centre opens to the south-west, not seaward, though before the eruption of the Stony Hill complex this would have been a seaward direction. The lava from Blineye is thought to have extended around the whole of its seaward margin, i.e. south-west around to south-east and east. The eastern part of the lava field and of the cone itself has subsequently been cut away by coastal erosion, leaving the beautifully exposed cliff section of Blineye.

Then followed, after an interval of unknown length, the eruption of the Stony Hill complex in several stages. The development of this complex is described in detail elsewhere (pp. 481 to 486).

The final stage of development has been the erosion of the south-western and southern margins of the Stony Hill lavas, and the building up of a boulder bank from Stony Beach Gulch along to Stony Beach, in front of the former marine cliffs eroded in Blineye cone. Much of the area is now covered with blown-sand deposits. Most of this sand has come from the Cave Gulch stream bed; above the Main Cliffs the alluvium in the floor of this Gulch has a high proportion of fine material. Much of the sand deposited where Cave Gulch crosses the coastal strip is loose and without vegetative cover and even previously stabilized dunes are now being reworked due to over-grazing.

2·4·4. *Sandy Point*

This lenticular area of low-lying ground is at the eastern extremity of the island, extends for about 1500 yards from just south of Big Gulch southwards to the East End of Sandy Point Gulch and is never more than 600 yards wide (figure 46, plate 24). Unlike the other coastal strips, Sandy Point is formed of pyroclastic debris with thick, but subordinate, flows of leucitic trachybasalt (for description see § 2·2·1 (*b*), figure 28, plate 20). Apart from a narrow sandy foreshore, the seaward margin is formed by two lines of cliffs. At the north end there is a line of low cliffs about 25 ft high which expose 1 or 2 trachybasalt lavas interleaving red scoria; above these cliffs the land rises in a gentle slope for a short distance before another line of cliffs exposes a similar sequence. These cliffs are about 100 ft. high and, at the southern end of the strip, are immediately behind the foreshore. Inland from the cliffs there is a relatively level grassy sward for about 300 yards; the land surface then steepens progressively until it merges with the Main Cliffs at about 700 ft., some 100 ft. below the edge of the Base. Numerous, deeply incised, V-shaped gullies traverse the strip from west to east and reveal that the bedding of the pyroclastic debris is not conformable with the overlying surface being, in most cases, inclined at a steeper angle.

Red ash, scoria and agglomerate associated with the Sandy Point parasitic complex are exposed within the main sequence in Big Gulch. Therefore, the strip does not represent part of a secondary pyroclastic centre erupted on the seaward margin of the Main Cliffs after they had been formed by marine erosion. The strip lies on the lee of the island where the Main Cliffs are only 800 ft. high. Furthermore, it can be seen that there is a marked embayment in the margin of the Base mirroring the limits of the coastal strip. It is suggested that in this sheltered position in the lee of the island marine erosion has not been as active as elsewhere allowing the formation of the Sandy Point strip by sub-aerial erosion. This erosion, particularly by scarp retreat at the head of the gullies, has caused the embayment in the Base which in turn allowed the formation of this limited area of low-lying ground.

2·5. *Petrography*

Although nearly all the crystalline rocks collected by the Expedition were sectioned and examined under the microscope, many are virtually identical or are so fine-grained as to preclude accurate definition. Furthermore, both Dunne (1941) and Campbell Smith (1930) have given detailed petrographic descriptions of rocks from the Tristan da Cunha Group. Therefore, the following descriptions are of rocks that have been chemically analyzed; they have been arranged numerically in sections corresponding with the major rock types, picrite basalts, alkali basalts, trachybasalts, trachyandesites and trachytes. It must be stressed that the variation in rock types is essentially gradational; definition of an individual specimen depending, in some cases, on the proportion of phenocrystic minerals present and in others on chemical rather than petrographic data (see figure 3).

Histograms, showing the frequency of major rock types in some of the various eruptive units and for the group as a whole are given in figure 9, and were compiled from an examination under the microscope of specimens collected by the Expedition. Stony Hill and the 1961 eruptive centre are not included in the compilation as these two areas were heavily oversampled. The trachandesites are, therefore, slightly underestimated. It is realized that this type of histogram probably gives a very biased picture of the volume relationships of the rock types and that they must therefore be used with caution. However, they do indicate the preponderance of basalt, and especially trachybasalt, over all other types and the more acidic nature of the material from the Peak compared with that from the Base and Main Cliffs. This latter observation was made by Dunne (1941, p. 16) and also by the Expedition when in the field.

A mineralogical feature of many of the lavas already noted (Le Maitre & Gass 1963) is the presence of interstitial leucite and rocks containing this mineral have been given the prefix 'leucite-bearing' or 'leucitic'. This presence of leucite is of particular interest as:

(*a*) It occurs interstitially and not as euhedral crystals which are typical of its occurrence elsewhere.

(*b*) It is an exceedingly rare mineral for oceanic islands only being recorded from Kerguelen (Edwards 1938), the Marquesas (Lacroix 1931) and from the Cape Verde Islands (Part 1950). In these instances both Kerguelen and the Cape Verde Islands are probably underlain by *sial* and are not, therefore, in a truly oceanic environment whilst the Marquesas occurrence is apparently a pseudo-leucite.

(*c*) It has apparently taken the place of nepheline in an essentially silica-undersaturated magma series.

Further work is being undertaken on this interesting problem and will be published at a later date.

In the following petrographic sections both the phenocryst and groundmass minerals are described in order of decreasing modal abundance.

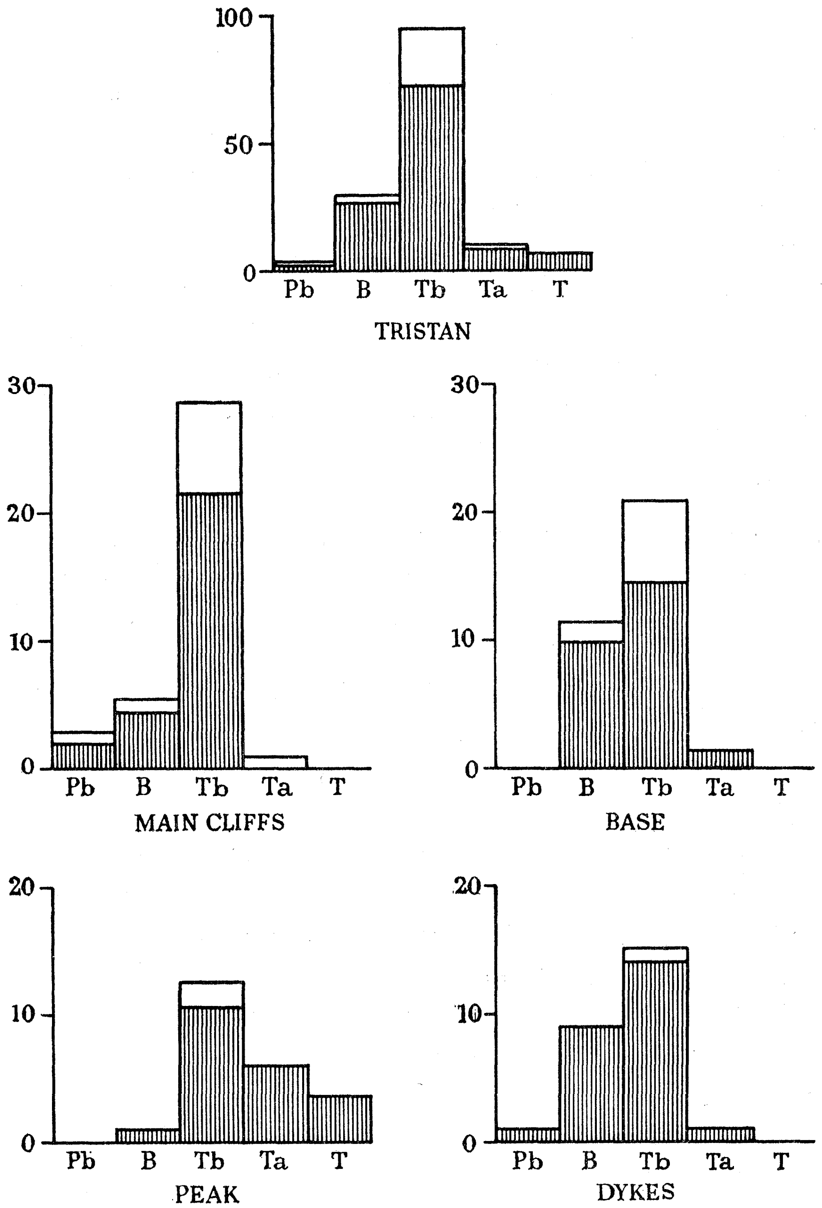

FIGURE 9. Histograms of major rock types. Pb = Picrite basalt, B = Alkali basalt, Tb = Trachybasalt, Ta = Trachyandesite, T = Trachyte. Unshaded areas represent leucite-bearing varieties.

2·5·1. *Picrite basalts*

These seem to be confined to ankaramitic types with phenocrysts of olivine and pyroxene in comparable abundance. They occur as both massive flows and dykes.

Ankaramite (114). Base of Main Cliffs East End of Sandy Point, 20 ft. O.D. In hand specimen this is a highly porphyritic rock with abundant phenocrysts of black pyroxene (up to 10 mm across) and less abundant yellow-brown olivine (up to 5 mm across) together forming 40 to 50% of the rock, set in a medium-grey aphanitic groundmass.

In thin section the phenocrysts can be seen to consist of pyroxene, olivine, plagioclase and iron ore (figure 68, plate 30). The pyroxene ($\beta = 1{\cdot}713$, $2V = 48°$) is a pale grey-green, slightly zoned diopsidic-augite. Although these phenocrysts are generally euhedral in outline many of them are embayed; inclusions of phenocrystic iron ore are common. The colourless olivine (Fa_{23}) is unzoned and perfectly fresh. It is euhedral to subhedral and often exhibits a good (010) cleavage. The plagioclase is progressively zoned from An_{85} in the cores to An_{45} at the margins, occurs as complexly twinned subhedral crystals (up to 1 mm long) and often occurs in aggregates. Slight normal zoning is common. Roughly equidimensional iron ore, up to 0·5 mm across, is also abundant.

The groundmass has an intergranular texture and consists essentially of plagioclase, pyroxene and iron ore. The plagioclase (An_{53}) occurs as a felted mass of laths up to 0·1 mm by 0·01 mm in size with abundant granular iron ore up to 0·02 mm in diameter and ill-defined, grey-green grains of pyroxene. Small crystals of olivine up to 0·02 mm across are present in minor amounts. In some areas the interstices are filled with cloudy isotropic material containing abundant needles of apatite.

2·5·2. *Alkali basalts*

These do not seem to be as abundant on Tristan as they are on many other oceanic islands. They occur as flows, dykes and intrusive masses and are usually either equigranular or slightly porphyritic. With increase of olivine and augite phenocrysts they grade into picrite basalts.

Alkali olivine basalt (6). Volcanic conduit in Main Cliffs 300 yards west of Caves Gulch, 100 ft. O.D. In hand specimen this rock is medium-grey in colour with a few small irregular vesicles. A few phenocrysts of black pyroxene and red-brown olivine up to 1 mm in diameter are visible.

In thin section the phenocrysts consist exclusively of olivine and pyroxene (figure 69, plate 30). The olivine (Fa_{21}) is euhedral to subhedral and frequently exhibits a good (010) cleavage; zoning is absent. Iddingsitization is slight and confined to cracks and narrow peripheral zones. The pyroxene ($\beta = 1{\cdot}711$ and $2V = 48°$) is a pale purple-brown titaniferous augite. It exhibits slight zoning; the rims, which are darker in colour than the cores, are occasionally crowded with inclusions of granular iron ore.

The groundmass consists of pyroxene, feldspar, iron ore and a minute amount of amphibole; olivine is entirely absent. The pyroxene is identical in appearance to the titaniferous augite phenocrysts and occurs as subhedral grains up to 0·1 mm in length. The plagioclase (An_{46} in the cores) exhibits slight normal zoning and occurs as small, well-defined and complexly twinned laths up to 0·1 by 0·02 mm in size. The iron ore occurs as roughly equidimensional grains approximately 0·05 mm across. In some of the interstices are patches of an isotropic substance, probably leucite, with low relief and a refractive index lower than Canada balsam and often containing a few highly acicular needles of apatite. A few ragged flakes of a brown amphibole and occasionally foxy-red biotite also occur throughout the groundmass.

2·5·3. *Trachybasalts*

These are by far the most abundant rock type and exhibit a considerable range of habitat and texture. They occur as flows, dykes, intrusive bodies and as scoriaceous material in cinder cones. Textural variations include a range from porphyritic to non-porphyritic types and from crystalline through extremely fine-grained to glassy varieties. Some specimens have marked fluidal textures and vesicularity is very variable. Many of these types contain interstitial leucite and these have been termed leucite-bearing trachybasalts.

As many of the extremely fine grained and glassy varieties defy definition by normal microscopic examination, eight specimens of varying appearance were selected for chemical analyses.

Highly vesicular trachybasalt (20). Small cinder cone just north of Big Sandy Gulch. This specimen is a piece of a scoriaceous pyroclastic block; it is so vesicular that the centre of the block has a 'spongy' appearance; near the margins the vesicles are smaller and are alined parallel to the outer surface. In the hand specimen the rock is dark grey and glassy with very occasional phenocrysts just visible to the naked eye. Under the microscope it is identical to specimen (21) described in more detail below.

Vesicular trachybasalt (21). West headland of Boat Harbour Bay. The specimen was taken from the ropy surface of a grey vesicular lava forming the base of the cliff section in this area. In hand specimen it is a dark grey aphyric rock with numerous small elongated vesicles. There are a few larger, highly irregular cavities associated with the rough ropy surface.

In thin section the rock can be seen to consist of plagioclase, pyroxene, a little olivine and iron ore, set in interstitial glass. The plagioclase laths, which measure approximately 0·2 mm by 0·02 mm, are roughly alined and tend to flow round the vesicles. They are albite and Carlsbad twinned and their cores are approximately An_{65}; zoning is slight and is confined to the extremities of the crystals. The pyroxene, which is euhedral to subhedral and rarely larger than 0·2 mm across, is pale grey-green in colour; there is slight evidence of zoning. The pyroxene is remarkably free from inclusions as is the colourless, perfectly fresh olivine, which occurs as small, often euhedral, crystals. Iron ore occurs as clusters of roughly equidimensional grains. A cloudy brown glass occurs interstitially. This rock, as well as being identical to specimen (20) in thin section, is also similar to specimen (622), a trachybasalt from the 'pillow' lavas of the foreshore immediately north of the Settlement. Specimens (20), (21) and (622) all came from parts of the Hillpiece parasitic centre.

Flow banded trachybasalt (117). Sandy Point, 100 yards north of East End of Sandy Point Gulch, 20 ft. O.D. In hand specimen this is a medium-grey aphanitic rock exhibiting well-defined 'flow' structures on weathered surfaces (figure 89, plate 33).

In thin section the rock has a few microphenocrysts of iron ore up to 0·5 mm across. The groundmass is intergranular and consists of plagioclase, iron ore, pyroxene and apatite. The flow bands which are easily visible in thin section when viewed with the unaided eye, become obscure when examined under the microscope, and seem to be due largely to a concentration of femic constituents. The plagioclase (An_{46}) occurs as a felted mass of well-defined laths up to 0·1 mm by 0·01 mm in size exhibiting very slight zoning and multiple twinning. Filling the interstices is granular iron ore up to 0·05 mm across and ill-defined granular pyroxene. A few flakes of a pale-brown, slightly pleochroic amphibole are also present. Hexagonal prisms of turbid apatite up to 0·1 mm across are also fairly plentiful.

Leucite-bearing trachybasalt (125). Noisy Beach, $\frac{3}{4}$ mile north of Lyon Point, 40 ft. O.D. In hand specimen this is a medium-grey aphanitic rock with a few small irregular vesicles. Pale-grey leucite-rich spots up to 1 mm in diameter cover about 10% of the surface and are particularly prominent on weathered faces. These spots are often arranged in roughly parallel lines giving the rock a flow-banded appearance.

Under the microscope the rock can be seen to contain a small number of microphenocrysts of faintly zoned plagioclase (An_{70}) and rare pyroxene. The groundmass has a fine-grained intergranular texture and consists of plagioclase, pyroxene, iron ore, a little olivine and leucite. The plagioclase laths which are frequently only simply twinned, exhibit a definite flow texture and are approximately 0·15 mm by 0·02 mm in size. They are strongly zoned, the composition of the cores being approximately An_{48}. Small granules of pyroxene, iron ore and occasionally olivine up to 0·01 mm in diameter occur in the interstices together with a few minute flakes of a medium-brown pleochroic amphibole and biotite. The pale-grey spots seen on the weathered surface are roughly rounded areas of groundmass where the interstices are completely filled with leucite ($n = 1{\cdot}508$). Where the areas of leucite attain any size they are frequently crowded with acicular needles of apatite and often exhibit weak birefringence and cross hatched twinning.

Leucite-bearing trachybasalt (194). Volcanic neck in Blineye parasitic centre, west end of Stony Beach (p. 480). This is a compact, medium-grey, aphanitic rock, a few phenocrysts of plagioclase and amphibole being visible in the hand specimen. One or two small plutonic xenoliths (up to 10 mm across) are also present.

In thin section the rock is mildly 'porphyritic' with 'phenocrysts' of plagioclase, resorbed amphibole, pyroxene and accessory iron ore and apatite (figure 71, plate 30). It is probable that many of the so-called 'phenocrysts' in this rock are xenocrysts derived from the plutonic xenoliths. The plagioclase (An_{43}) occurs as anhedral crystals which are complexly twinned and slightly zoned especially at the margins. The amphibole is almost completely resorbed and is now represented by iron ore, pyroxene and feldspathic material. From the shape of these aggregates and from remnants within them, the original amphibole was a dark-brown anhedral basaltic hornblende. The pyroxene ($\beta = 1{\cdot}720$, $2V = 52°$) is anhedral and is a pale purple-brown titanaugite frequently containing small dust-like inclusions of iron ore. Roughly equidimensional crystals of iron ore up to 1·0 mm in diameter and euhedral apatites full of dust-like inclusions are also present.

The groundmass has a very fine grained intergranular texture and consists of plagioclase, iron ore, pyroxene, leucite and sodalite. The plagioclase (An_{40}) consists of a felted mass of ill-defined laths up to 0·1 mm by 0·01 mm in size. Granular iron ore up to 0·02 mm in diameter and rounded elongated crystals of pyroxene up to 0·05 mm by 0·02 mm occur abundantly throughout the groundmass. Minute flakes of biotite (?), pleochroic from colourless to medium red-brown, are also present in small quantities. Under a low-power objective, in both plane polarized light and crossed nicols, the groundmass has a spotty appearance. The 'spots' are roughly circular, up to 0·5 mm in diameter and consist of a concentration of femic constituents and leucite. The leucite occurs interstitially within the spots and also infills small cavities. It is weakly birefringent ($n = 1{\cdot}506$), exhibits polysynthetic twinning and is crowded with fine acicular needles of apatite. Some of this material was separated and the leucite confirmed by X-ray powder photographs. Sodalite was also identified from this rock crush by X-ray powder photographs and optics ($n = 1{\cdot}485$), but was not positively identified in thin section, probably due to its rarity.

Trachybasalt (347). Flow forming waterfall in Pigbite Gulch, 600 ft. O.D. In hand specimen it is a medium-grey compact rock with moderately abundant small phenocrysts of black pyroxene up to 5 mm across and plagioclase up to 1 mm in length.

The microscope reveals that the pyroxene ($\beta = 1{\cdot}717$, $2V = 50°$) is a euhedral pale-purple-brown titaniferous augite. The smaller plagioclase phenocrysts are also euhedral and slightly zoned from An_{85} to An_{80}. Equidimensional phenocrysts of iron ore up to 1 mm across are quite common and small subhedral crystals of olivine are also present. All the phenocrysts are remarkably free from inclusions.

The groundmass is intergranular in texture and consists of plagioclase, pyroxene and iron ore. The plagioclase (An_{54}) occurs as small slightly zoned laths measuring 0·1 mm by 0·02 mm and exhibiting a definite parallel alinement. Abundant granular iron ore, approximately 0·005 mm in diameter, and pyroxene occur between the feldspar laths while the interstices are filled with small quantities of alkali feldspar and leucite.

Leucite-bearing trachybasalt (351). Small plug 100 yards east of summit crater lake, 6550 ft. O.D. (p. 467). In hand specimen this is a massive, slightly porphyritic rock with phenocrysts of black, elongated amphibole up to 5 mm long, black pyroxene up to 1 mm across and plagioclase laths up to 2 mm long, set in a medium-grey aphanitic groundmass. On weathered surfaces the groundmass is dotted with pale-grey, leucite-rich spots up to 1 mm in diameter.

In thin section the phenocrysts consist of partially resorbed amphibole, pyroxene and plagioclase. The amphibole ($\beta = 1{\cdot}697$; $2V = 73°$; $\gamma \wedge c = 4° \pm 1°$) has the pleochroic formula: $X =$ pale yellow-brown; $Y =$ medium brown; $Z =$ dark brown; and is similar in appearance to the basaltic hornblende occurring in the plutonic xenoliths (p. 501). It is surrounded by a reaction rim up to 0·2 mm thick consisting of granular iron ore, feldspar and a pinkish pyroxene (?) which exhibits a marked dispersion; adjacent to the reaction rim the amphibole is markedly darker in colour. The pyroxene ($\beta = 1{\cdot}717$, $2V = 53°$) is probably a slightly titaniferous augite. It frequently exhibits simple twinning and is euhedral to subhedral. Inclusions of iron ore are not uncommon. The plagioclase, which is complexly twinned, is strongly zoned from An_{80} to An_{70}. It is subhedral to euhedral in outline and frequently crowded with dust-like iron ore in the outer zones of the crystals.

The groundmass has an intergranular texture and consists of plagioclase, pyroxene, iron ore, leucite and alkali feldspar. The plagioclase (An_{68}) occurs as a felted mass of narrow laths approximately 0·1 mm by 0·01 mm which often only exhibit simple twinning. Both the pyroxene and iron ore tend to be granular with an average diameter of 0·01 mm. In certain areas of the groundmass the interstices are filled with alkali feldspar often crowded with minute acicular needles of apatite. In other rounded areas the interstices are filled with leucite ($n = 1{\cdot}506$) which is also commonly crowded with minute acicular needles of apatite. Leucite also occurs in small veins and cavities in the rock where the typical 'cross-hatched' twinning is exhibited (figure 72 and 73, plate 30).

Trachybasalt (364). Prominent lava forming interfluve to east of Hottentot Gulch, 5400 ft. O.D. In hand specimen it is a dense, slightly porphyritic rock with phenocrysts of pyroxene up to 3 mm across and plagioclase up to 2 mm across, set in a medium-grey aphanitic groundmass.

Under the microscope the euhedral to subhedral pyroxene ($\beta = 1{\cdot}716$, $2V = 51°$) is very pale, purple-brown in colour and is probably a titaniferous augite. It commonly contains inclusions of iron ore. The plagioclase phenocrysts are slightly zoned from An_{86} to An_{80} and tend to have corroded outlines; many contain zones of dust-like inclusions of iron ore. Equidimensional phenocrysts of iron ore up to 0·4 mm in diameter are moderately abundant.

The groundmass consists of a felted mass of ill-defined plagioclase laths (An_{40}) between which are abundant granules of iron ore up to 0·005 mm in diameter, pyroxene and olivine (?). The interstices are filled with alkali feldspar.

Trachybasalt (369). Prominent columnar jointed lava high in the cliffs overlooking the north end of Stony Beach, 1800 ft. O.D. In hand specimen this is a compact, dark blue-grey, aphanitic rock with a few small phenocrysts of pyroxene and plagioclase.

In thin section the sparse phenocrysts can be seen to consist of plagioclase, pyroxene and iron ore. The plagioclase (An_{46}) is anhedral and only slightly zoned. The pale-grey-green pyroxene is also anhedral and like the plagioclase is rarely larger than 0·5 mm across. Crystals of resorbed basaltic hornblende also occur but are probably xenocrysts.

The groundmass is intergranular and very fine grained, consisting of plagioclase, pyroxene, iron ore and amphibole. The plagioclase consists of minute laths, 0·05 mm by 0·005 mm, arranged in a subparallel manner with minute granules of iron ore up to 0·01 mm and rounded, elongated crystals of colourless pyroxene up to 0·01 mm by 0·002 mm. Crystals of a pale-brown, pleochroic amphibole occur as irregular flakes up to 0·2 mm in the groundmass and commonly growing into cavities where they are associated with alkali feldspar. The groundmass also has a spotty appearance; the spots, which are up to 0·5 mm in diameter, are due to a concentration of femic constitutents together with a certain amount of cloudy isotropic material (leucite?).

Trachybasalt (504). Dyke in East Molly Gulch just below Stony Castle, 4000 ft. O.D. This is a compact medium grey aphanitic rock with no phenocrysts visible in the hand specimen.

Under the microscope it can be seen to be sparsely microporphyritic with small phenocrysts of a purple-brown titaniferous augite up to 0·3 mm across. The groundmass consists of plagioclase, pyroxene, iron ore and a little olivine. The plagioclase (An_{46}) occurs as multiply-twinned laths up to 0·4 mm by 0·02 mm exhibiting a poorly defined flow structure. Slight normal zoning is present. The pyroxene is of the same type as the microphenocrysts and occurs as rounded prismatic grains up to 0·1 mm across, occasionally with inclusions of iron ore. The iron ore is present as abundant euhedral grains which have an average diameter of 0·05 mm. Euhedral fresh olivine is present in very minor amounts and a little alkali feldspar is present in some of the interstices.

Scoriaceous trachybasalt (619). Inside west crater wall, Frank's Hill. This specimen, which is a highly vesiculated, dark-grey aphanitic rock, is part of a pyroclastic block in the walls of the crater. The vesicles are irregular and although mainly about 0·5 mm in diameter, occasionally are as much as 5 mm across.

In thin section the rock contains a few small sporadic phenocrysts of purple-brown titaniferous augite. The groundmass is partially crystalline consisting of slender laths of plagioclase up to 0·1 mm by 0·005 mm, minute granules of iron ore up to 0·001 mm across and elongated grains of pyroxene, slightly smaller than the plagioclase laths, set in a purple-brown glass. A few small grains of olivine (?) are also present in the groundmass.

Trachybasalt (622). Foreshore, immediately north of Settlement. This specimen, which is a compact, dark grey aphyric rock with flattened, elongated vesicles up to 5 cm in length, was taken from one of the bolster-like entrail lavas, 8 in. from the outer margin of a 'bolster' (p. 487).

Under the microscope the rock can be seen to consist of plagioclase, pyroxene, iron ore and a little olivine set in a pale-brown glass. The plagioclase laths, which are rarely larger than 0·5 mm by 0·01 mm, have a markedly preferred orientation. They are nearly all twinned according to the albite and Carlsbad laws and from extinction angle measurements on these two twin laws the composition of the cores was found to be An_{75} to An_{65}; the margins of the laths are strongly zoned to a much more sodic plagioclase. The pyroxene occurs as very pale grey-green subhedral crystals and is only slightly zoned; occasionally, it has inclusions of iron ore but these are rare. The olivine, which is colourless and perfectly fresh, is definitely subordinate to the plagioclase and pyroxene both in size and abundance. Iron ore occurs as roughly equidimensional grains up to 0·1 mm across; these often occur in aggregates and also as very fine feather-like crystals, approximately 0·01 mm by 0·001 mm, in the clear purplish-brown interstitial glass. The olivine and iron ore occur in about equal amounts.

2·5·4. *Trachyandesites*

These are the main rock types in the secondary effusive centres (for petrographic descriptions see sections on Stony Hill and the 1961 parasitic centre, pp. 481 and 539) and also occur as flows within the main sequence and probably as dykes. The positive identification of this type in thin section only is often very difficult and it is possible that some of the rocks recorded as trachybasalts fall into this group. They are usually slightly porphyritic and tend to be highly vesicular especially in the effusive types.

Porphyritic trachyandesite (572). Lava (bottom of flow), west side of 2nd Ridge-where-the-goat-jumped-off, 2500 ft. O.D. In hand specimen this a porphyritic rock with abundant phenocrysts of white plagioclase up to 3 mm across, black elongated amphiboles up to 5 mm long which often occur in clots, and black plates of biotite up to 1 mm across, set in a light-grey aphanitic groundmass.

In thin section the phenocrysts can be seen to be plagioclase, amphibole, biotite, iron ore and a little pyroxene and apatite (figure 76, plate 31). The plagioclase (An_{65} in the cores) exhibits normal zoning and is often rimmed by a thin layer of alkali feldspar. It is subhedral with complex twinning and frequently occurs as glomerocrysts. The amphibole ($\beta = 1{\cdot}712$, $2V = 73°$) is mildly pleochroic with: $X =$ yellow-brown; Y and $Z =$ dark-brown. It is apparently in equilibrium and may be a barkevikitic hornblende. It is euhedral to subhedral, remarkably fresh and is practically unzoned. The biotite ($\beta = 1{\cdot}676 \pm 0{\cdot}005$, $2V = 28°$) occurs as blocky tablets and is strongly pleochroic from brown to dark red-brown. It shows very slight signs of resorption. Roughly equidimensional iron ore up to 0·5 mm across is common. Apatite and a very pale grey-green pyroxene also occur.

The groundmass consists of a felted mass of ill-defined laths of alkali feldspar which in some places exhibit flow structure but elsewhere are randomly orientated. Minute needles of colourless pyroxene with an average size of 0·03 mm by 0·003 mm and euhedral grains of iron ore up to 0·006 mm across are scattered liberally throughout the groundmass.

2·5·5. *Trachytes*

Trachytes occur mainly as intrusive bodies, more rarely as lava flows. They are frequently porphyritic and tend to be non-vesicular. Mineralogically, they are divided on the basis of their phenocrystic feldspar into two groups: plagioclase trachytes and alkali feldspar trachytes. Some of these late differentiates tend to have a slight phonolitic tendency and in one specimen (30) nepheline occurs as phenocrysts.

Phonolitic alkali feldspar trachyte (30). Compact intrusive mass associated with sandy horizon 400 yards west of the settlement quarry, foot of Main Cliffs, 150 ft. O.D. (p. 465). In hand specimen this is a buff-coloured rock with abundant small phenocrysts of pale-yellow nepheline up to 0·5 mm across and an occasional phenocryst of alkali feldspar up to 2 mm in diameter.

The microscope reveals that the phenocrysts consist of nepheline, alkali feldspar and minor sphene. The nepheline ($\omega = 1{\cdot}534$) occurs as euhedral, hexagonal prisms with a coating, up to 0·02 mm thick, of a yellow alteration product (figure 84, plate 32). Needle-like inclusions of pyroxene are common. The alkali feldspar ($\beta = 1{\cdot}532$, $2V = 53°$) occurs as subhedral laths with a patchy extinction. There are some very fine exsolution blebs of a more sodic phase. The euhedral sphene is not as abundant as it is in the alkali feldspar trachyte number 31.

The groundmass is very cloudy and consists of ill-defined alkali feldspar laths, yellow elongated grains of aegirine-augite and iron ore.

Alkali feldspar trachyte (31). 10 yards east of specimen 30. In hand specimen this trachyte is a compact, very pale pink-grey rock with a slightly speckled appearance; just discernible with the naked eye are phenocrysts of alkali feldspar.

In thin section the phenocrysts can be seen to consist of alkali feldspar up to 2 mm across and iron ore and sphene, both up to 1 mm in diameter. The alkali feldspar ($\beta = 1{\cdot}531$, $2V = 48°$) is present as euhedral to subhedral laths often occurring in clusters. It has a patchy extinction and exhibits slight signs of exsolution of a more sodic phase. Sphene occurs as euhedral crystals and for an accessory mineral is moderately abundant as is the equidimensional iron ore.

The groundmass has a very fine trachytic texture and consists of alkali feldspar, aegirine-augite and iron ore. The alkali feldspar laths are extremely ill-defined with a marked patchy extinction and are full of dust-like inclusions. The aegirine-augite is oxidized and occurs as extremely ragged, yellow crystals often poikilitic but sometimes present as bundles of very fine needles. The iron ore is liberally scattered throughout the groundmass. A colourless isotropic mineral (sodalite?) occurs quite frequently as a coating to the alkali feldspar laths in certain areas and also as discrete crystals where it is sometimes associated with small crystals of nepheline.

Plagioclase trachyte (560). Volcanic plug on the south-eastern flank of the Peak, 4900 ft. O.D. This is a compact porphyritic rock with lath-like phenocrysts of colourless plagioclase up to 8 mm long and black elongated pyroxenes and amphiboles up to 2 mm long set in a light-grey, aphanitic groundmass. The phenocrysts exhibit a remarkably distinct foliation.

Under the microscope phenocrysts of plagioclase, amphibole, pyroxene, iron ore and sphene were identified. The plagioclase (An_{61}) occurs as slightly rounded, but well-formed, complexly twinned laths. Slight oscillatory zoning is present and a thin rim of alkali feldspar is often present. The amphibole ($\beta = 1{\cdot}706$, $\gamma \wedge c = 6°$) is a euhedral to subhedral dark brown basaltic hornblende and is always partially resorbed to a mass of granular iron ore; inclusions of apatite are common. The pyroxene ($\beta = 1{\cdot}708$, $2V = 59°$) is a pale-green aegirine-augite and occurs as euhedral to subhedral, slightly elongated crystals. Slight zoning is present and inclusions of iron ore and acicular needles of apatite are common. Euhedral crystals of sphene up to 0·5 mm long and prismatic apatite also occur but are less common than the roughly equidimensional crystals of iron ore which are up to 0·5 mm in diameter.

The groundmass consists of blocky laths of moderately zoned alkali feldspar up to 0·2 mm by 0·02 mm, needles of pale-green pyroxene whose average size is 0·1 mm by 0·01 mm and euhedral grains of iron ore up to 0·01 mm across. The foliation detectable in the phenocrysts is also displayed in the groundmass.

2·6. *The plutonic xenoliths*

Xenoliths of plutonic aspect occur abundantly on Tristan and are found in lava flows of the main sequence, in lavas and pyroclastic material of the secondary centres and in volcanic necks and dykes. Notable examples are those in the lava flows at Sandy Point, Molly Gulch, and Gipsy's Gulch, in the lava of the 1961 parasitic eruption, and in the pyroclastic debris from the Burntwood, Hackel Hill and Blineye parasitic centres. They were also found in abundance in loose blocks of lava and scoria on the coast at the northern end of Stony Beach Bay.

These xenolithic blocks, although having an average diameter of 10 cm, range from as much as 25 cm to mere xenocrysts a few millimetres across. Mineralogically, they vary from leucocratic types with up to approximately 90% feldspar to extremely melanocratic types with virtually no feldspar; the leucocratic varieties are, however, much less common. Equally striking is the variation in grain size, from specimens where the average grain size is 1 mm or less to those where it is nearer 5 mm; in the latter type, individual crystals of some minerals, particularly the amphibole may be several centimetres in length, giving the rock a pegmatitic aspect. Layering is present in some of the specimens (e.g. 676) where feldspathic layers alternate with more melanocratic bands, each layer averaging about 6 mm in width. Sometimes the layering manifests itself in the form of differences in grain size; in one specimen, for instance, long amphiboles of crescumulate habit with large plagioclase crystals extend for several centimetres parallel to a band which contains the same minerals but in a markedly finer grain size. This same specimen shows an even finer grained vein cutting across both of the other layers. In some of the melanocratic specimens the feldspar is restricted to narrow schlieren-like streaks and patches.

Plutonic xenoliths from the Tristan da Cunha Group have previously been described by Campbell Smith (1930) and Dunne (1941) and a brief examination of the present collection, amounting to nearly 250 specimens, largely confirms their observations. Mineralogically, they are relatively simple consisting essentially of plagioclase, clinopyroxene, amphibole and iron ore, in all proportions. Apatite, biotite and sphene occur as accessory minerals. It is interesting to note that olivine is very rare and hypersthene absent altogether, unlike the gabbroic xenoliths from Gough and Ascension.

The plagioclase is usually fairly fresh although in a few specimens it does have a typical metamorphic 'dusting' of iron ore. It has a composition in the labradorite–bytownite range and in some xenoliths it is slightly zoned. The corroded cores and glassy networks seen in the plagioclase of many of the lavas do not appear to be present.

The clinopyroxene is similar in appearance to the titanaugites of the lavas. The colour varies from xenolith to xenolith between pale-purply-brown and greeny-grey; in a few cases individual crystals are zoned from one colour to the other, the greener variety usually forming the rims. In many instances, and in particular in those xenoliths from pyroclastic centres the pyroxene is patchily altering, in an orientated manner, to a brown amphibole; all stages of alteration can be seen. Iron ore is sometimes present as exsolved rods and blebs.

The amphibole is pleochroic from pale-yellow (X) through deep-orange to foxy red-brown (Z) and is similar in appearance to the amphibole seen in many of the trachybasalt and trachyandesite lavas. Dunne (1941, p. 48) has referred to this amphibole as kaersutite. It commonly occurs as discrete blade-shaped crystals and in most of the xenoliths found in the tuffs and cinder cones is remarkably fresh; occasionally the edges of the crystals are very much darker in colour than the cores. In the xenoliths found in effusive rocks the amphibole is usually altered to a granular mixture of ilmenite, a reddish pyroxene (referred to by Dunne (1941, p. 53) as rhoenite) and plagioclase. In many of the xenoliths this alteration has been carried to completion and at this stage the xenolith is usually about to break up into xenocrysts.

The iron ore occurs mainly as large irregular masses or more rarely as discrete grains. Apatite is locally abundant and occurs as large single crystals, often slightly rounded; inclusions of minute rods of iron ore giving it a dusty appearance are not uncommon. Biotite occurs as a secondary mineral and there is a tendency for it to occur in the xenoliths derived from tuffs and cinder cones.

3. The Nightingale Group

3·1. *Introduction*

Three main islands, Nightingale, Middle or Alex, and Stoltenhoff, together with numerous islets and off-shore rocks, form the Nightingale Group that lies 21 miles SSW of Tristan. Existing maps of the group show very considerable variation in the shape and disposition of the islands and none agrees closely with the radar trace made by H.M.S. *Protector* in March 1962. The geological sketch map, figure 10, is based on *Protector*'s radar trace amended in places where further, more detailed information is available; especially useful in this respect were photographs taken from *Protector*'s helicopter. On the three

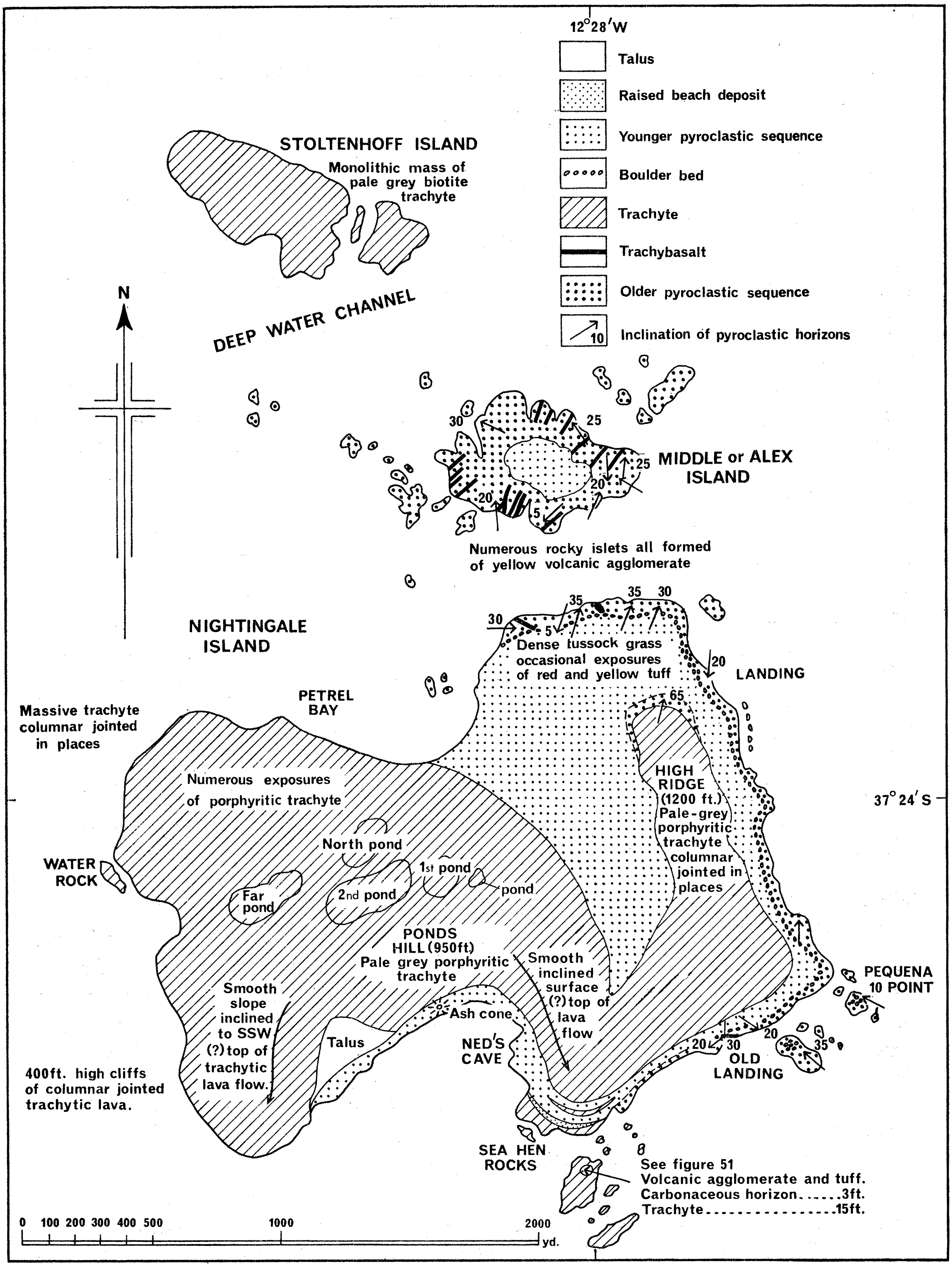

FIGURE 10. Geological sketch map of the Nightingale Group.

larger islands a thick cover of tussock grass up to 10 ft. high hampers movement and masks rock outcrops. Exposures are seen only in the sea-cliffs, where they are often covered with species of green and orange algae, and on the steeper faces of the inland topography.

3·2. *Nightingale Island*

The thick mantle of vegetation and the insufficient time available prevented the detailed examination of Nightingale Island; the geological description given below is acknowledged to be inadequate in detail. It is, however, thought that it adds to the limited information available about the geology of this island. Furthermore, the interior of the island has never been surveyed and the topographic features and geological boundaries depicted on figure 10 are only sketched.

Nightingale, the largest island of the group, is roughly rectangular in shape, has a planar area of just over 1 sq. mile and consists of two tracts of high, rocky country separated and partially surrounded by low-lying, densely vegetated ground. As indicated on figure 10 the twofold topographic division into high and low ground is directly related to the geology, the upland masses being formed of massive trachyte whilst the lower ground consists primarily of less resistant volcanic ash and agglomerate. The two upland areas are separated by a north–south valley that traverses the whole island (figure 50, plate 26). High Ridge is the local name for the tract of high ground that forms the eastern part of the island. This ridge is never more than 250 yards wide and extends north–south for about 1000 yards and rises to a height of 1300 ft. The topography of the high ground to the west is more complex, being formed of numerous small hills separated by basins occupied by swampy lakes, locally known as the 'Molly Ponds'. In the absence of any definite information the position of these ponds on figure 10 must be, at best, conjectural. The western mass culminates in a small eminence to the south of the 'Molly Ponds'. No local name has been assigned to this feature; herein it will be referred to as Ponds Hill.

The sea-cliffs surrounding Nightingale vary considerably in height; to the north, north-east, east and south-east, volcanic agglomerate forms low cliffs varying between 30 and 150 ft. in height whilst to the north-west, west and south-west, massive columnar jointed trachyte forms near vertical cliffs as high as 600 ft.

3·2·1. *Geology*

The geology of Nightingale is dominated by two rock types; yellow volcanic ash and agglomerate, and large, virtually structureless masses of porphyritic trachyte. On the available evidence it is tentatively suggested that there are at least three major stages present. The oldest rocks are yellow volcanic ashes and agglomerates; these have been invaded by trachytic intrusions from which thick lavas of the same composition have flowed. Subsequently, after a period of erosion, the trachytic masses and the older pyroclastic material have been overlain by volcanic debris similar in most respects to the older agglomerates, ashes and tuffs.

The envisaged sequence of events is given in table 3.

The older pyroclastic sequence crops out in the northern and eastern sea-cliffs of Nightingale and also forms most of Middle Island. The exposures examined in detail are in the vicinity of the *landing* (see figure 10) and extend from the north-easternmost point of the island southwards for about 300 yards to a point immediately below the island hutments. Here, the sequence consists of well-bedded, pale yellow volcanic agglomerate dipping mainly between 30° and 40° to the north-east. At the eastern extremity of this outcrop a dip of 30° to the east was recorded whilst below the hutments a southerly dip of 20° is dominant. It seems likely that this inclination represents the depositional dip of volcanic debris ejected from a number of pyroclastic centres.

TABLE 3

raised beaches	
period of erosion	
younger pyroclastic sequence	material varying in texture from fine ashes to coarse agglomerate locally interbedded with thin horizons rich in plant remains
period of erosion	formation of extensive boulder bed, the main material being trachyte identical to the trachyte plugs
intrusion and extrusion of trachyte masses	
older pyroclastic sequence	mainly yellow volcanic agglomerates issuing from various centres and cut by numerous basic dykes

The agglomerate consists of angular fragments of trachyte, trachyandesite and trachybasalt which vary in diameter from 2 to 50 cm together with smaller pieces of pumiceous trachyte and scoria and fine-grained volcanic ash. Both the pumiceous trachyte and the scoria contain perfectly euhedral crystals of aegirine-augite and separate crystals of this mineral are occasionally found within the agglomerate. The bedding of this pyroclastic sequence is accentuated by the varying degrees of hardness of individual horizons. Softer, less well-consolidated horizons are eroded whilst the harder layers stand out as low ridges. On examination, the varying degree of consolidation can be seen to be directly related to the proportion of scoria present. Horizons consisting mainly of lithic fragments are generally soft, friable and poorly cemented, whilst when a high percentage of scoriaceous lapilli is present these have welded together, cementing the rock into a more compact mass.

At the extreme northern end of High Ridge, immediately above the level ground covered with thick tussock grass, is an outcrop of volcanic agglomerate identical in composition and texture to that exposed at the landing. Here, the inclination of the well-bedded agglomerate is 65° to the NNE. This angle is obviously too high to be entirely depositional; as the main mass of the High Ridge trachyte crops out immediately to the south, it is thought with some confidence that the steep inclination is due to the invading trachyte dragging up the agglomerate around the margins of the intrusion.

Cutting the older pyroclastic sequence, but not seen elsewhere, are narrow sinuous dykes of trachybasalt. On Nightingale these intrusions are rare and were only found in three localities: to the north-west of the landing, at the north end of High Ridge and in the sea-cliff section above the old landing. At sea-level, about 100 yards west of the landing, there is a small isolated exposure of basic material some 10 ft. in diameter. On field relations this mass is obviously intrusive and is formed of altered porphyritic, leucite-bearing trachybasalt. The rock contains phenocrysts of pyroxene and rare phenocrysts of olivine, some of which are pseudomorphed by hematite and analcime (?), set in a fine grained groundmass of pyroxene, labradorite and analcime (?). A similar basic intrusion is exposed some 150 yards to the north-west. This body is irregular but dyke-like in form and varies from 5 to 10 ft. in width. This basic intrusion cuts yellow volcanic agglomerate, has a chilled margin of about 6 in. and is formed of altered trachybasalt similar in all respects to the rock described above. A very thin basic dyke is exposed at the northern extremity of High Ridge where it can be seen to cut yellow volcanic agglomerate. This is a dark-grey, aphanitic trachybasalt (401) containing occasional phenocrysts of pyroxene. In thin section the rock is fine grained with a definite flow texture. The plagioclase laths (An_{45}) are approximately 0·15 mm by 0·015 mm and often show only simple twins. Pyroxene occurs interstitially as minute granules ($< 0·01$ mm) and also as relatively rare crystals of size comparable with the plagioclase. Also in the interstices are granules of iron ore ($< 0·01$ mm), unidentifiable ferromagnesian material and a few residual patches of leucite.

Sporadic phenocrysts of pyroxene and plagioclase (both $< 0·5$ mm), rare xenocrysts of resorbed basaltic hornblende and occasional fragments of trachyte also occur.

The analysis of this rock is given in table 6, facing p. 520.

The dyke behind the old landing is more regular in form, but once again the host rock is volcanic agglomerate of the older pyroclastic sequence.

The trachytes of Nightingale form High Ridge and the Ponds mass, and crop out along the south coast where they also form numerous off-shore islets. Good exposures, often over 100 ft. high, can be seen on the flanks of High Ridge. Here, the trachyte is usually structureless although a well developed near-vertical columnar structure is displayed in isolated outcrops. Exposures on the Ponds mass are confined to the summits and steeper slopes of the numerous small hills that surround and lie between the 'Molly Ponds'.

In both these areas the structureless form of the trachyte suggests that the masses are of intrusive origin. This is supported by the near-vertical contact between the trachyte and the older pyroclastic sequence at the north end of High Ridge. Near the top of High Ridge there are strongly developed horizontal partings which might be joints or alternatively might represent horizontal trachytic flows. The main rock type of High Ridge is a soda-rich trachyte, consisting of phenocrysts of plagioclase and aegirine-augite set in a fine-grained felted groundmass. Specimens collected from the Ponds area are all of porphyritic trachyte although there is limited variation in the proportion of the phenocrysts present; for the main part plagioclase is the dominant porphyritic mineral whilst in some specimens aegirine–augite, basaltic hornblende and biotite are present as phenocrysts. Massive trachyte with well-developed near-vertical columnar jointing forms the high western cliffs of the island; these undoubtedly belong to the mass that forms the Ponds area.

Three of the Nightingale trachytes, specimens 412, 420 and 439, were analyzed, see table 6. Specimen 412 was taken from the Ponds area, 220 yards north-east of North Pond and is a plagioclase trachyte which has a porphyritic appearance; phenocrysts of white plagioclase, dark brown amphibole, both up to 5 mm across, and pyroxene set in a light brownish-grey aphanitic groundmass.

In thin section the phenocrysts can be seen to consist of plagioclase, pyroxene, highly resorbed basaltic hornblende and apatite (figure 82, plate 32). The plagioclase (An_{37}) is subhedral and complexly twinned; it is slightly zoned and occasionally rimmed with a thin layer of alkali feldspar. The pyroxene is zoned from a pale-purple titaniferous augite to a greeny aegirine-augite but not apparently in any regular manner; the β refractive index is the same for both (1·704), but $2V$ is slightly higher in the aegirine-augite, 59° as opposed to 57°. The basaltic hornblende ($\beta = 1{\cdot}725 \pm 0{\cdot}003$; $\gamma \wedge c = 4°$) is always highly and often completely resorbed, being surrounded by a rim of opaque material. Small phenocrysts, up to 0·5 mm, of rusty brown apatite also occur.

The groundmass consists of a felted mass of rather ill-defined alkali feldspar laths (0·1 mm by 0·01 mm), granules of pale green aegirine-augite and deep red hematite (?).

Specimen 420, taken from the north end of High Ridge, is a compact porphyritic rock with phenocrysts of black amphibole and pyroxene, and plagioclase, all up to 5 mm across, set in a light blue-grey aphanitic groundmass.

In thin section the phenocrysts were identified as plagioclase, pyroxene, resorbed basaltic hornblende and apatite. The plagioclase (An_{39}) is slightly zoned and commonly rimmed by a thin zone of alkali feldspar; it is complexly twinned and euhedral to subhedral in form. The pyroxene ($\beta = 1{\cdot}709$, $2V = 60°$) occurs as euhedral, slightly elongated crystals of pale-green aegirine-augite. A second generation of pale-green elongated pyroxene crystals (up to 0·3 mm) also occur. The basaltic hornblende is nearly always completely resorbed. Elongated crystals of turbid apatite are sparingly present.

The groundmass consists of blocky crystals of zoned alkali feldspar, often with inclusions of dust-like iron ore in their cores, small grains of frequently euhedral iron ore up to 0·01 mm across and minute (0·01 by 0·002 mm) rodlike crystals of yet another pyroxene.

The suggestion has been made (Douglas 1930) that the roughly circular depressions of the 'Molly Ponds' are volcanic craters. The morphology of these ponds is vaguely reminiscent of such craters. However, in many cases the outline of the Ponds is extremely irregular and also there is no sign of any explosion products in the vicinty. In the absence of any definite evidence to the contrary, it is suggested that these Ponds are erosional features and not explosive in origin (figure 53, plate 26).

Along the southern coast of Nightingale, trachytic lavas, between 20 and 100 ft. thick and virtually identical in hand specimen to the rocks that form High Ridge and the Ponds mass, are found beneath a sequence of tuffs. When viewed from the air these trachyte flows can be seen to be columnar jointed in places and to form a sheet-like mass inclined to the south at between 5° and 10° that extends from the Ponds southwards almost to the coast. It is likely that this mass represents a trachytic lava flow which extruded from the Ponds area.

Specimen 439, an alkali feldspar trachyte, was taken from the columnar jointed lava that underlies the tuff horizons on the hardies off Sea hen Rocks (see figure 51, plate 26). In hand specimen this rock appears to be coarse grained but it is actually porphyritic with abundant phenocrysts of white feldspar, up to 10 mm across, and occasionally black elongated pyroxenes (up to 3 mm long) set in a light-grey crystalline groundmass.

In the thin section examined, the phenocrysts consist of alkali feldspar, aegirine-augite, iron ore, sphene and zircon (figure 83, plate 32). The alkali feldspar ($\beta = 1{\cdot}530$, $2V = 50°$ to 55°, O.A.P. $\sim \perp$ (010)), occurs as tabular crystals often in composite groups; twinning is not abundant and there are some 'blebs' of an exsolved sodic feldspar present. Aegirine-augite crystals, although not abundant, have a β refractive index of 1·712 and are green in colour and elongated. Iron ore, sphene and zircon occur as accessory phenocrystal minerals. The groundmass consists of a mass of blocky and felted lath-like crystals of alkali feldspar with granules of pale-green aegirine-augite and iron ore.

A *Boulder bed* composed almost entirely of well-rounded pebbles and boulders of porphyritic trachyte crops out in the eastern cliff section of the island and extends from the northernmost point southwards as far as the old landing (figure 52, plate 26). This horizon lies between 15 and 100 ft. above sea-level and varies in thickness from 1 to 15 ft. The lower surface, that rests unconformably on the older pyroclastic sequence, is extremely irregular, rounded boulders of the horizon commonly being found in crevasses within the agglomerate to a depth of about 15 ft. The upper surface is more regular having a gentle seaward inclination. The trachytic boulders and pebbles vary in size from 1 to 50 cm, are extremely well rounded and often appear polished, are well cemented by a medium-grained, sub-angular sand of similar composition. In thin section they are similar, in all respects, to the trachytes that form High Ridge and the Ponds mass. Occasional pebbles of fine-grained trachybasalt were found; these are very similar in thin section to the trachybasalt dykes that cut the older pyroclastic sequence.

Lying on the truncated top of the older pyroclastic sequence and overlain by a younger sequence of volcanic tuffs and agglomerates, this boulder bed represents a period of quiescence in the volcanic history of Nightingale during which the trachytic intrusives of High Ridge and the Ponds mass were exposed to erosion. The well-rounded polished nature of the boulders, the unsorted nature of the deposit and the highly irregular underlying surface all suggest that this boulder bed is a fossil beach deposit. It is interesting to note that it does not occur on Middle Island although the division between the older and the younger pyroclastic sequence is well displayed.

The younger pyroclastic sequence is the name designated to those pyroclastic deposits and other interbedded material that lie unconformably on all the older units described above. Rocks of this sequence floor the valley between High Ridge and the Ponds area, crop out above the boulder bed on the eastern coastal section and occur in the narrow coastal strip that flanks the south coast of the island. This sequence was examined in detail in two places, in the cliff section above and to the west of the landing, and on the south coast in the vicinity of Sea hen Rocks.

In the exposures near the landing the lowest beds lie either on the boulder bed or directly on coarse agglomerates of the older pyroclastic sequence. This lowest horizon consists of well-stratified sandy tuff which dips southwards at about 5°. This horizon, particularly conspicuous owing to its bright yellow colour, is some 7 to 8 ft. thick and gradually grades upwards into coarse volcanic agglomerate. The deposit is an even-grained, loosely consolidated tuff whose pyroclastic origin is indicated by occasional euhedral crystals of plagioclase feldspar. Some of the exposures show weakly developed cross-bedding. This, together with the well-bedded nature of the deposit as a whole, suggests that it was laid down in shallow water. The abundance of plant remains found elsewhere indicates that the depositional environment could have been lagoonal. The agglomerates overlying the tuff horizon are exposed in the area of the hutments; they are similar in most respects to the agglomerates of the older pyroclastic sequence but are generally less well consolidated.

On the south coast, at Sea hen Rocks, the younger pyroclastic sequence is well exposed. The sequence of table 4 was measured

TABLE 4

	(ft.)
Sea hen tuff	25
trachytic lava	18
fine tuff with abundant plant remains and numerous ash partings	10
raised beach deposit	15
weathered trachyte	30

The boulder bed does not occur at this locality, the raised beach deposit overlying the weathered trachyte is thought to represent the period of volcanic quiescence reflected by the boulder beach elsewhere. The weathered trachyte that forms the base of this section is related to the intrusive trachytes exposed farther inland. Immediately overlying the raised beach is a 10 ft. sequence of fine ashes with abundant carbonaceous plant remains. This horizon is probably equivalent to the fine-grained sandy tuffs that crop out at the landing and a lagoonal environment is envisaged for both sequences. The age of a specimen rich in plant remains has been determined by the radiocarbon method as $39\,160^{+6090}_{-3410}$ years B.P. The lava overlying this tuff, although trachytic, differs from the High Ridge trachytes in hand specimen and it is thought to represent a lava which issued from a mainly pyroclastic parasitic centre. Above the lava there are some 25 ft. of bedded ash and agglomerate similar in most respects to that exposed near the landing.

At the hardies off Sea hen Rocks the lowest rocks exposed are trachytes. This is a vertically jointed trachytic lava flow and is overlain by about 10 ft. of sandy tuff containing abundant plant remains. In this locality the plant remains are so numerous that the horizon could in part be regarded as a lignite. A sequence of yellow agglomerates dipping to the west at about 10° overlies the carbonaceous horizon (figure 51, plate 26). A quarter of a mile west of Sea hen Rocks the remnants of a small cinder cone are to be found on the narrow coastal strip. This undoubtedly is one of the parasitic explosion centres that provided the material for the younger pyroclastic sequence.

3·3. *Middle Island*

Lying to the north of Nightingale and separated from it by a 300-yard wide, rock-strewn channel is the low-lying mass of Middle Island with its numerous off-shore rocks (figure 48, plate 25). Steep cliffs surround the island whilst the interior is relatively flat and covered by high, dense, tussock grass; it is only around the coast that good exposures are to be found. The offshore rocks are all constantly awash and support no vegetation. Middle Island itself and the nearby rocks are composed of yellow volcanic ash and agglomerate that has been invaded by a north-easterly basic dyke swarm. The geological sequence is identical with that exposed in the north-eastern part of Nightingale; the oldest rocks are coarse, yellow agglomerates belonging to the older pyroclastic sequence. These have been cut by the basic dykes and all have been unconformably overlain by a fine-grained sandy tuff identical with the lowest horizon of the younger pyroclastic sequence on Nightingale Island. The yellow agglomerates and tuffs of the older pyroclastic sequence form the bulk of Middle Island and all the offshore islands. The agglomerate consists of a heterogeneous assemblage of rock fragments mainly trachytes but with some trachybasalt present. On the north coast this pyroclastic material has a northerly dip of between 20° and 30° whilst at the south end of Middle Island the beds are steeply inclined to the south at up to 60°. Similar material is recognized inland where it forms small hillocks and ridges which rise some 50 ft. above the general level of the island.

The trachybasalt dykes, which have a dominant east-north-easterly trend, are numerous and are particularly well exposed on the west coast. Usually vertical, they represent several phases of injection for at numerous localities they can be seen to have cross-cutting relationships.

On the south coast at about 150 ft. above sea-level there is a series of fine, brown, sandy tuffs showing thin sensitive stratification. These beds are horizontally disposed, unconformably overlie the steeply dipping tuffs and agglomerates of the older pyroclastic sequence and appear to be of lagoonal origin.

3·4. *Stoltenhoff Island*

Stoltenhoff is separated from Middle Island by a deep water channel about 600 yards wide. It is a roughly oval, monolithic mass of biotite trachyte whose maximum dimensions are 750 yards east–west and 300 yards north–south (figures 48 and 49, plate 25). Over 90% of the monolith is one island surrounded entirely by 300 ft. high vertical cliffs. At the east end of this island are two smaller masses, both obviously once part of a single unit but now separated by deep, narrow defiles produced by marine erosion along major joint lines. The flat top to the mass is covered with tussock grass but excellent exposures are to be seen in the sea cliffs. These cliffs, stained in places by orange algae, have weathered to a pale grey.

The major joint pattern can be seen to be orientated to 020°; a secondary joint direction trends at 100°. On the northern cliffs of the main mass there is sporadic development of rude, vertical, columnar jointing (figure 49, plate 25). No layering can be seen and it is most probable that the island represents a monolithic, dome-like intrusion similar to that forming High Ridge on Nightingale and, on a smaller scale, South Hill on Inaccessible Island.

Owing to adverse weather, it was not possible to land on Stoltenhoff. Dunne (1941, p. 81) describing a specimen of the Stoltenhoff trachyte from the north-west part of the island some 10 m. above sea-level states:

'The rock consists of phenocrysts of zoned plagioclase An_{85-40}, strongly pleochroic biotite, diopsidic augite and occasional anorthoclase set in a groundmass of alkali feldspar laths, small colourless augite crystals, minute cubes of magnetite and a few flakes of biotite. Occasional sphene, magnetite and apatite are the accessories.'

4. Inaccessible Island

4·1. *Introduction*

Lying 22 miles south-west of Tristan and bounded, almost entirely, by near vertical cliffs varying in height between 500 and 1800 ft., Inaccessible Island fully justifies its name (see figure 54, plate 27). Even under ideal conditions landing is rarely possible on the south, south-west and south-east sides of the island. During the Expedition's visit it was, however, possible to land at Salt Bay on the north side of the island and at Blenden Hall, the western extremity of Inaccessible; petrographic descriptions given below are of specimens taken from the Salt Bay area. In addition, examination of cliff exposures was made from a motor boat at a distance of about 100 to 350 yards off-shore, and subsequently from a helicopter flying level with the cliff tops at a similar distance.

Combining the information provided by Dunne (1941), who worked mainly in the Blenden Hall area, a reasonable picture of the geology of Inaccessible can be presented, although detailed correlation of the various rock types is not possible.

In the absence of aerial photographs, the existing maps of Inaccessible vary very considerably in their representation of the form of the island, although some additional data were provided by a radar trace of the island made by H.M.S. *Protector*. Therefore, figure 11, a compilation based on all available evidence, is probably in error.

In plan, the island is roughly rhomboidal with the northern shore, especially, having numerous shallow indentations. The east–west diameter is about 3 miles, the shorter north-south diameter some $2\frac{1}{2}$ miles; the planar area is $3\frac{3}{4}$ sq. miles. In section, the island has a relatively smooth, gently inclined upper surface whose altitude gradually increases from east to west, the maximum height (1800 ft.) being reached immediately above Blenden Hall (see section on figure 12).

Dunne (1941) records that the densely vegetated upper surface of Inaccessible has a relatively flat, undulating topography formed by a shallow central basin and a few minor conical hillocks. Fleeting glimpses of this surface from a helicopter through an almost complete cloud cover confirmed Dunne's description. Drainage channels appear to be relatively sinuous and to occupy V-shaped valleys whilst the surface cinder cones display the steep-sided gullying already described for some such areas on Tristan. The cones are relatively well preserved and there seems little doubt that sub-aerial erosion has only slightly modified their original constructional surfaces.

For about 2 miles offshore the waters round Inaccessible are shallow (less than 100 fathoms, see figure 2). The only offshore islet of note is Pyramid Rock, off South Hill, where a trachyte dome with magnificently developed, near-vertical, arcuate columnar jointing rises abruptly from the sea to a height of over 250 ft. (figure 55, plate 27).

4·2. *Geology*

Inaccessible, surrounded by an extensive shallow water platform, is almost certainly an eroded remnant of a once much larger volcanic island. The form of the island itself, with its relatively flat top, the gentle eastward inclination of the lava flows, the breached cinder cone on the upper surface, the trend of the dykes and the extent of the shallow water platform, suggest that the now roughly rhomboidal island represents the relatively

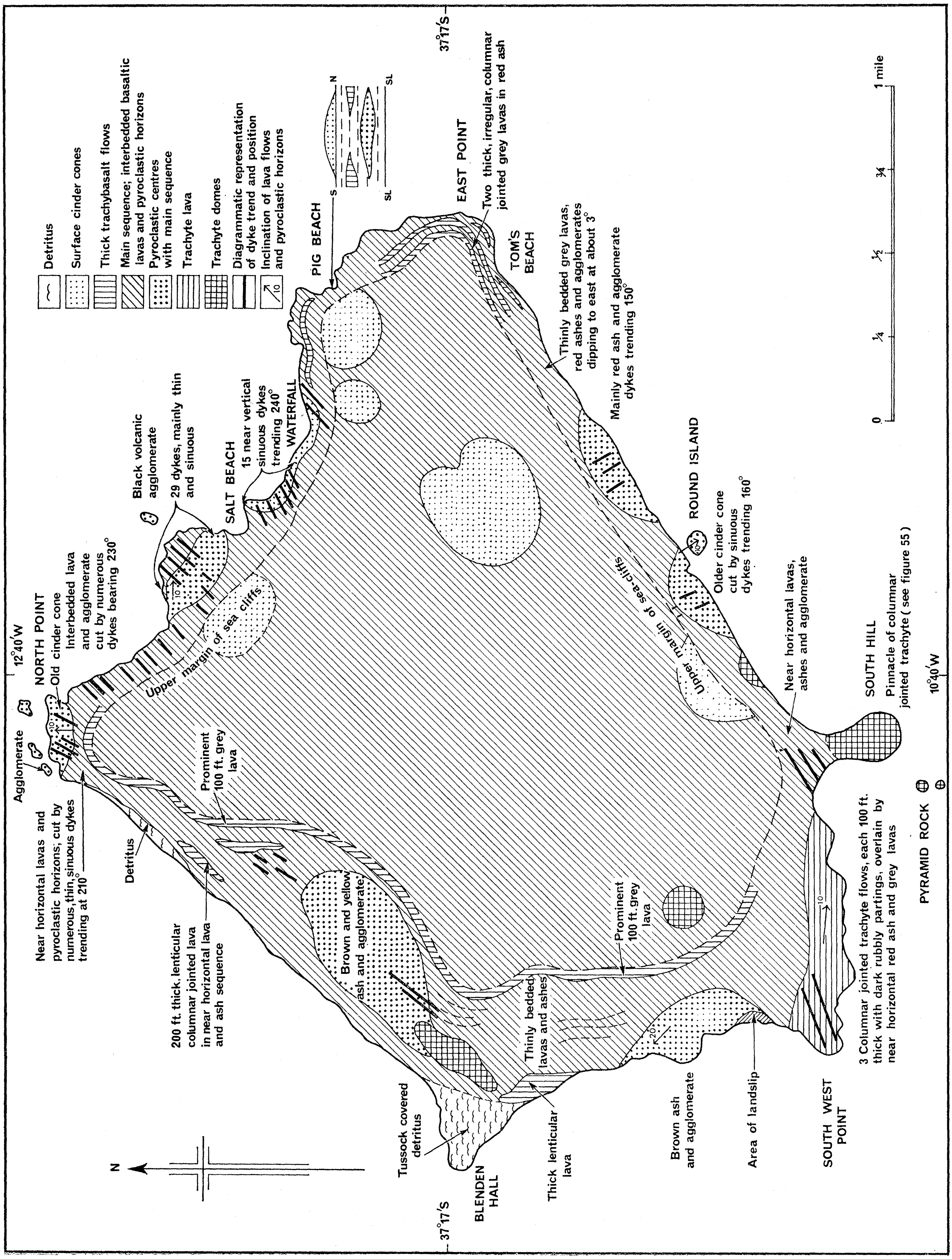

FIGURE 11. Geological sketch map of Inaccessible Island, partly after Dunne (1941).

undissected eastern part of a once nearly circular volcanic cone. The postulated position of the island with respect to the original volcanic cone is schematically represented in figure 12.

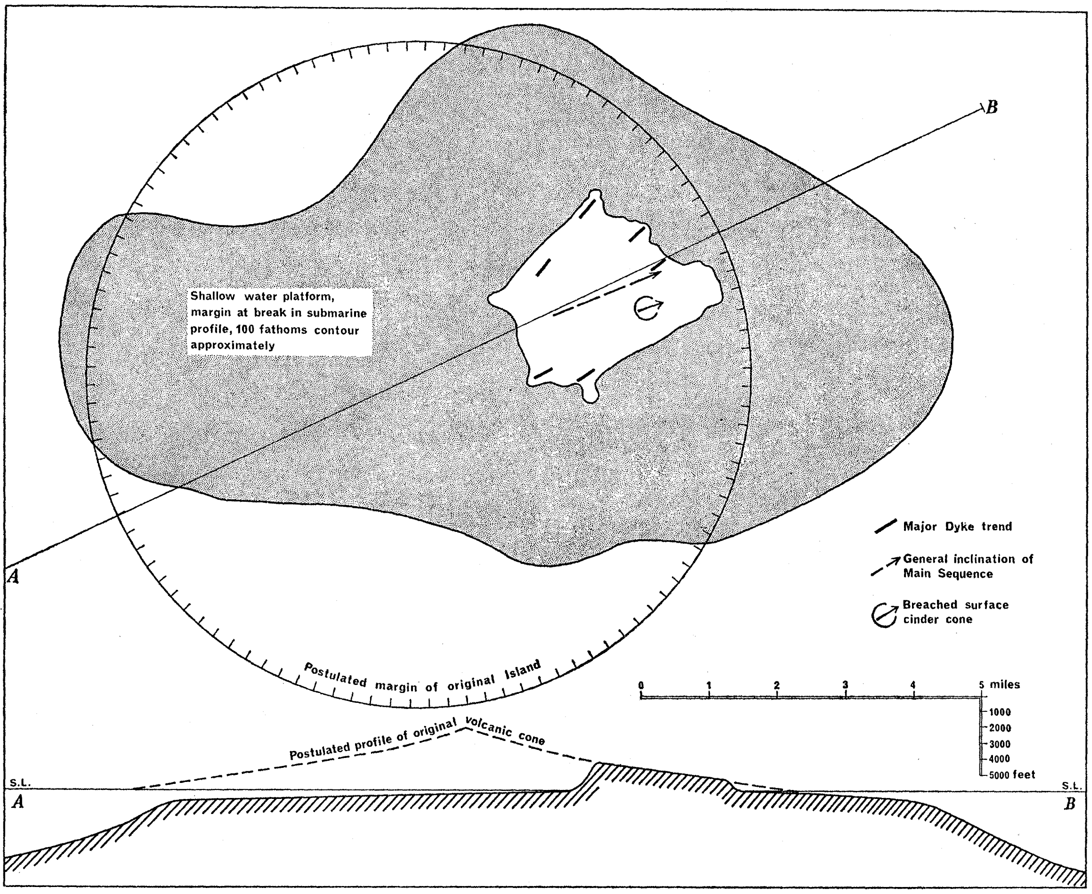

FIGURE 12. The postulated position of Inaccessible with respect to the original volcanic island.

The erosional state of Inaccessible is mid-way between that of Tristan and the nearby island of Nightingale. Like Tristan, Inaccessible consists mainly of basaltic lavas with interbedded rubble and pyroclastic horizons and with well-formed parasitic cinder cones lying on the upper surface. Parasitic cinder cones are also found within the lava sequence and are well exposed in the sea-cliffs. Dykes with dominant north-easterly and easterly trends are numerous, especially along the north coast between North Point and Pig Beach. The resemblance to Nightingale is more marked on the south-east coast where trachytic plugs crop out at Blenden Hall, South Hill and Pyramid Rock, and thick, near-horizontal, trachytic lavas form the sea-cliffs between South Hill and South-West Point.

It is difficult to present the geology of Inaccessible in a chronological sequence as the age relationship between the various rock types is by no means certain. It is apparent that trachytic domes and thick lavas are the dominant rocks in the south-west and thinly bedded basaltic lavas with numerous minor parasitic cinder cones are the dominant features elsewhere. At the top of the cliffs are thick flows of trachybasalt composition. It is possible that the south-west coast exposes the more central parts of the original volcano. This, however, has not been proved, and it is therefore thought advisable to describe the geology in lithological units. The major subdivisions, in probable age sequence, are listed below:

surface pyroclastic centres
trachybasalt lavas
dykes
parasitic pyroclastic centres
main basaltic lava sequence
trachytic domes and lavas

(the last three: at about the same period)

4·2·1. *Trachytic domes*

Exposed in the sea-cliffs between Blenden Hall and Round Island are a number of spectacular trachytic domes whose existence was first recorded by Dunne (1941). During the expedition these domes were viewed from a motor-boat lying offshore and a brief visit was made to the Blenden Hall area on the morning of 21 March 1962.

During the examination of the sea-cliffs from offshore, trachytic plugs were identified at Blenden Hall, Pyramid Rock, South Hill and in the cliffs some 400 yards east of South Hill. The Blenden Hall dome protrudes from the lower part of the cliff immediately behind the low promontory of Blenden Hall itself. It has been intruded into a near-horizontal lava-agglomerate sequence and is overlain in turn by a similar sequence of extrusive rocks. The dome forms a smooth, exfoliated, convex rock-face some 300 ft. high in marked contrast to the other trachytic domes that have well-developed columnar jointing (figure 56, plate 27). Seen from offshore but not visited were the striking trachytic plugs that form South Hill and Pyramid Rock. Both these conical masses are steep sided, rising directly from the sea to a height of about 700 and 250 ft. respectively. The rock weathers to a pale-grey and both rock masses display extremely well-developed, near-vertical, arcuate columnar jointing. Pyramid Rock rises as a monolithic mass from the sea, but the South Hill mass has been intruded into a near-horizontal sequence of grey lavas and reddish pyroclastic material. To the west of South Hill for a distance of $\frac{1}{2}$ mile there is a series of thick, pale-grey, near-horizontal, columnar jointed lavas which appear identical at a distance with the trachyte at South Hill itself. These masses are thought to represent trachytic lavas which issued from conduits such as South Hill. Their form and disposition will be discussed later.

Some 400 yards east of South Hill, at the base of the cliffs, there is a small trachytic mass which appears to have been intruded into the surrounding extrusive rocks. From a distance this rock is identical to South Hill, although it does not display columnar jointing. In addition to this mass, Dunne states that there is a small trachyte dome exposed at the top of these cliffs (see figure 11).

Petrography. The petrography of the Blenden Hall dome has been described by Dunne (1941). Only the lower parts of this mass were examined by the writers. Here, the trachyte is a leucocratic rock with scattered phenocrysts of feldspar and biotite clearly visible in the hand specimen. An irregular banding is visible in the rock expressed as slight variations in the colour from grey to a very pale whitish-grey. One band was observed to contain a higher proportion of dark minerals than those on either side; this feature is probably the result of flowage during emplacement.

Examination in thin section shows large phenocrysts of plagioclase, brown biotite and alkali feldspar, and very occasional rather ragged phenocrysts of greenish clinopyroxene. The plagioclase phenocrysts tend to occur as glomeroporphyritic groups up to about 5 mm in diameter, are faintly zoned, have a composition of approximately An_{43} and have been subject to mechanical dislocations, having been veined along the fractures with glass and a reddish-brown mineral which is probably chiefly hematite. Phenocrysts of alkali feldspar are smaller than the plagioclases and sometimes show a $2V$ as low as 50° supporting Dunne's view that anorthoclase is present. Alkali feldspar is sometimes found mantling an earlier formed plagioclase, but more often the two are found as intergrowths. Biotite forms the principal dark mineral. Presenting a ragged anhedral outline, the biotite shows a speckled appearance when at extinction, which is at an angle of about 3° to the cleavage traces. The biotite is generally resorbed at its margins. The occasional phenocrysts of augite have a $2V$ (+) of 58°. The groundmass consists of a feathery textured mass of plagioclase and alkali feldspar laths together with haematite and occasional zircons. The smallest plagioclases have a composition of approximately An_{25}.

4·2·2. *Trachytic lavas*

Trachyte lavas are exposed in the high sea-cliffs between South-West Point and South Hill for a distance of about ½ mile. There are three lava flows; each is about 100 ft. thick, has well-developed vertical columnar jointing, is separated from the overlying flow by a reddish rubbly horizon and is inclined to the east at about 10°. Although the inclination of these flows is given as 10°, this is an average figure for the attitude of the flows undulates gently between 5° and 12°, always maintaining an easterly dip. The columnar jointing is orientated perpendicular to the inclination and therefore accentuates the undulose attitude of the flows. These thickly bedded trachytic lavas give way eastwards to an interbedded lava and agglomerate sequence and are also overlain by near-horizontal, thinly bedded, basaltic lavas with tuffaceous horizons.

These lavas were only seen from the sea and it was not possible, owing to adverse weather conditions, to collect specimens. They are termed trachytic mainly by comparison with similar trachytic flows on Nightingale Island and as they appear identical to the trachytic masses at South Hill and Pyramid Rock, and because the individual pillars of the columnar jointing between the lavas and the domes are of comparable horizontal dimension. As these flows are inclined to the east, it is thought that they were extruded from a volcanic centre that lay to the west of Inaccessible Island.

4·2·3. *Main basaltic lava sequence*

The sea-cliffs of Inaccessible are formed of thin flows of basalt with rubbly tops and bottoms intercalated with occasional horizons of yellow and red volcanic ash. Above Salt Bay there are about 130 individual flows with an average thickness of 5 ft. In other parts of the island a similar sequence is apparent. True pyroclastic material forms only about 10 % of the total sequence. These flows are gently inclined at between 3° and 5° to the east and are virtually identical in form and composition to the lavas of the main sequence on Tristan. As on Tristan, the majority of flows are basaltic varying from basalts through olivine basalts to ankaramites.

Only the cliff face in the area of Salt Bay was examined in detail and here it seems that ankaramite lavas were more common than on Tristan. This, however, may not be applicable to the whole island although the wealth of this more basic lava was noted by Dunne.

Petrography. For descriptive purposes the lavas have been divided into (*a*) olivine basalts, and (*b*) ankaramites.

(*a*) Generally compact and medium grey in the hand specimen, the *olivine basalts* contain phenocrysts of olivine, pyroxene and plagioclase, all of which are visible to the naked eye. The olivines are euhedral in outline, and are slightly altered to iddingsite. Measurements of the $2V$ indicate a composition of approximately Fa_{23}. The large clinopyroxenes, often containing inclusions of ore, are pale-brown in colour, sometimes with a suggestion of pink. Slight zoning is evident in the variation in the $2V$ from approximately 57° at the core to 54° at the margin. Plagioclase phenocrysts have a prismatic habit and are zoned from approximately An_{60} at the core to An_{40} at the rim. The groundmass of these basalts is generally pilotaxitic, the feldspar microlites being associated with granular pyroxene and ore. Conspicuous in the olivine basalt from Salt Beach is a distinctive mica. Probably of xenocrystic origin, the mica has an extinction angle of approximately 3° and shows strong pleochroism from a deep orange brown (Z) to colourless (X). It may be allied to phlogopite in composition.

(*b*) In the Inaccessible *ankaramites*, the pyroxenes attain a diameter of 1 cm and are associated with subsidiary olivine and plagioclase phenocrysts. The following is a modal analysis of a typical ankaramite: plagioclase phenocrysts 6·8; olivine phenocrysts 7·8; pyroxene phenocrysts 26·5; groundmass 58·9.

In thin section, the olivines are subhedral, frequently show alteration to iddingsite at the margins and invariably contain inclusions of ore. They are occasionally mantled by clinopyroxene. Measurements of the optic axial angle indicate a composition of approximately Fa_{17}. The pyroxenes, usually a pale greenish-brown colour, become slightly pink towards the crystal margins. The optic axial angle varies from approximately 59° at the core to 52° at the rim. The plagioclase phenocrysts are smaller than the ferromagnesian minerals and tend to occur in glomeroporphyritic groups. They are sometimes composed of faintly zoned labradorite, others are strongly zoned, the cores having a composition of An_{80} and the rims An_{55}.

The groundmass is often largely glassy, but when microcrystalline consists of plagioclase laths (An_{50}), pyroxene granules and ore.

Some other ankaramites are more olivine rich. A typical example has the following modal constitution: olivine phenocrysts 13·3; pyroxene phenocrysts 17·7; groundmass 67·0. Large pyroxenes (7 mm) and olivines (4 mm), the only phenocrysts, are set in a dark aphanitic groundmass. The olivines are well formed, often euhedral in outline, but frequently show alteration to hematite along fractures and at the margins. They generally contain inclusions of ore. Zoning is occasionally conspicuous, the composition ranging from approximately Fa_{15} at the core to Fa_{30} at the margin. The pyroxenes are pale-brown to slightly pink in colour and not infrequently poikilitically enclose small rounded olivine crystals and ore granules. The $2V$ ranges from approximately 58° at the core to 55° at the margin. The dense groundmass is composed of a high proportion of very minute plagioclase laths (An_{60}) associated with granular pyroxene, ore and glass.

4·2·4. *Parasitic pyroclastic centres*

As on Tristan, numerous, mainly pyroclastic parasitic centres are found within the main lava sequence. In all, ten such centres were identified and these are depicted on figure 11. As exposed, these cones vary in diameter from 400 yards to ½ mile and in height from 200 to 800 ft. The largest centre crops out on the western cliffs immediately north of Blenden Hall. Here, brown volcanic ash and agglomerate occupy the majority of the cliff face for a distance of ½ mile. The other cinder centres are formed of red ash intermingled with tenuous basaltic lavas. Flows associated with these parasitic cones are generally thin and inclined at between 10° and 25°.

Petrography. Scoriaceous basaltic material collected from a parasitic centre ½ mile east of North Point is described below:

It is striking for the abundance and size of the olivine phenocrysts which attain as much as 5 mm in diameter. Large feldspars are of similar magnitude.

In thin section the rock is seen to consist of phenocrysts of olivine, plagioclase and less abundant pyroxenes in a dense, glassy groundmass; the olivine and pyroxenes sometimes occur as glomeroporphyritic groups. The plagioclase phenocrysts show zoning from a large core of An_{65} to a rim of An_{45}. Some of the phenocrysts have been severely dislocated, perhaps in the explosive discharge of the lava, and brown glass now occurs along the fractures. The large subhedral olivines have also been subject to mechanical displacements and the brown glass again fills the fractures and cavities so formed. The composition of the olivines is approximately Fa_{13}. The largest olivines poikilitically enclose smaller rounded olivines of different optic orientation, as well as small unzoned plagioclases (*ca.* An_{70}). In some cases a slight zoning is detectable within the olivines, but this is usually evident only towards the margin. Inclusions of ore are common. Clinopyroxene phenocrysts show the same degree of fracturing and incorporation of glass as the olivines. They occasionally contain small inclusions of olivine, and have a $2V$ of approximately 58° (+). The groundmass is dense and glassy, with abundant ore, plagioclase microlites and pyroxene granules. The specimen is highly vesicular and vesicles occur up to about 1 cm in diameter. Some of the smaller vesicles contain zeolites. The mineral has a somewhat fibrous habit, low birefringence and a refractive index very close to that of Canada balsam, suggesting a composition close to that of thomsonite.

4·2·5. *Dykes*

Numerous dykes are exposed in the sea-cliffs of Inaccessible, where they stand out as thin, vertical, white stripes cutting the near-horizontal lavas and rubble horizons which are of a darker colour (figure 54, plate 27). Most of the dykes are thin, varying between 3 in. and 6 ft. in width, are locally sinuous, and tend to occur in swarms where the ratio of dyke to country rock is as high as 1:10. Only rarely does a single dyke traverse the entire vertical outcrop, more often a single unit will split into two branches and many can be seen to pinch out at both ends. Between the swarms, dykes tend to be wider and more continuous; one such intrusion, 35 ft. wide, crops out south of Blenden Hall. Dunne records that on the south-west of the island there is a stockwork of dykes which have replaced nearly three-quarters of the country rock. At North Point a recent landslip lays bare an outcrop measuring 100 yards east–west and over 150 ft. high; in this area thirty individual dykes with an average width of 2 ft. were counted. Farther to the east in the small promontory west of Salt Beach twenty-nine dykes crop out within a horizontal distance of 350 yards. On the south side of the island between South Hill and Tom's Beach, dykes are relatively common but tend to become rarer towards the east. At the eastern extremity of the island dykes are only seen rarely and are confined to the lower parts of the sea-cliff.

When viewed from a distance there is a tendency to plot the trend of the dykes perpendicular to the cliff face. In many cases it was possible to define the trend of these intrusive bodies, and these trends are indicated on figures 11 and 12. On the north coast between North Point and the waterfall, the dominant trend is south-westerly, whilst at Blenden Hall, Dunne records a west-southwesterly trend which was also recorded for the dykes cutting the trachytic lavas at South-West Point. On the south coast, east of South Hill the cliffs are relatively smooth and a three-dimensional picture cannot easily be obtained. There is, however, a general impression, borne out by isolated outcrops, that the dominant dyke trend is north-westerly.

Petrography. As exposed in the Salt Bay area, the dykes of Inaccessible can be conveniently grouped into (*a*) ankaramites, (*b*) olivine basalts, and (*c*) basalts; groups (*b*) and (*c*) commonly have abundant xenocrysts, which tends to complicate the classification.

(*a*) Three ankaramite dykes were located in the Salt Bay area. In the hand specimen these rocks are seen to contain a large number of olivine and pyroxene phenocrysts in roughly equal proportions; they sometimes occur as glomeroporphyritic clusters in a dark vitreous groundmass. Some specimens are sparingly vesicular.

Under the microscope olivine phenocrysts of up to 3 mm in diameter are usually found to be fresh although incipient alteration to iddingsite is sometimes observed. Their composition, based on measurements of $2V$, ranges from Fa_{20} to Fa_{13}. The clinopyroxene phenocrysts which are of a similar size and abundance to the olivines, have a $+2V$ of *ca.* 57°. Occasionally poikilitic association of rounded olivine within clinopyroxene may be seen. Very rarely plagioclase phenocrysts make an appearance; they are invariably corroded, fracture and filled with glassy inclusions. Faint zoning may be present, but the average composition is about An_{70}. The groundmass consists of glass, plagioclase microlites (An_{50}), ore and pyroxene granules.

(*b*) As the proportion of olivine and pyroxene phenocrysts diminishes and plagioclase becomes increasingly abundant, the term olivine basalt becomes more appropriate. In specimens containing abundant plagioclase, this mineral tends to occur in stellate clusters, often containing many glassy inclusions, and is frequently severely fractured; the plagioclase is only slightly zoned, having large cores of labradorite *ca.* An_{60}. The olivine phenocrysts are euhedral to subhedral in outline, are scarcely altered, and have a composition of Fa_{13-15}. The clinopyroxenes occur both in glomeroporphyritic groups together with the olivines, and as individual phenocrysts. They are a pale greenish-brown for the most part though a pinkish tinge becomes prominent towards their margins; the $2V$ is approximately $+55°$. Strongly pleochroic green and brown amphiboles occur in occasional specimens; the green variety has a $2V$ of approximately 80° and an extinction angle $\gamma \wedge c$ of approximately 15°. Biotites up to 3 mm in diameter also appear in isolated specimens. Pleochroic in shades of pale brown to greenish-brown, this mineral invariably possesses a corona of granular ore. Large phenocrysts of ore, up to 1 mm in diameter are also present. The groundmass usually consists of plagioclase microlites of composition An_{40-50} associated with granular pyroxene and ore; there is usually very little glass.

(*c*) The remaining basalt dykes are generally equigranular, consisting essentially of plagioclase laths and pyroxene granules with subsidiary glass. The larger plagioclases are zoned with a composition ranging from An_{60} to An_{40}. The smallest plagioclase crystals have a composition of An_{40}. The pyroxenes are a pale brownish-green colour with sometimes pinkish margins; they are probably of titanaugite composition. With one exception these dykes carry xenocrysts which can be grouped into olivine and clinopyroxene, and hornblende, plagioclase and apatite clusters.

4·2·6. *Trachybasalts*

Thick, pale grey, columnar jointed lavas often with lenticular cross-section are common in the volcanic sequence exposed in the sea-cliffs in Inaccessible. Dunne describes these lavas under the heading of 'Thick Flows of the East' and indicates that they are of trachybasalt or olivine-trachyandesite composition and possibly flowed from parasitic centres. Specimens of these flows were not obtained, but their form and disposition were studied from the sea. It seems that on form alone this group can be subdivided into (*a*) thick lenticular flows rarely more than 500 yards wide but often thickening to as much as 150 ft. within this distance, and (*b*) continuous lava flows occurring near the top of the succession varying between 50 and 150 ft. in thickness which are always columnar jointed and maintain a regular attitude.

Although occurring throughout the succession, the lenticular masses are mainly associated with red pyroclastic deposits and seem, as Dunne suggested, to be associated with explosive volcanic activity from parasitic vents. Similar flows of trachybasalt on Tristan also appear to be associated with secondary pyroclastic centres (p. 462). These masses are best displayed on the south-east and east coasts of Inaccessible and have been extruded on numerous occasions during the volcanic history of the island.

Extending from North Point to South Hill and capping the western sea-cliffs is a thick, near-horizontal, grey, columnar jointed lava which varies in thickness from 100 to 150 ft. Once again, no specimens were obtained but the surface appearance indicates that the masses are of similar composition to the lenticular flows described above. Similar regular lavas crop out at the eastern end of the island and it seems that this lava sequence was one of the last events in the volcanic history of Inaccessible and that the easterly inclination of the flows would suggest that they came from a major vent that existed to the west of the island. The relative youth of these flows is indicated by the fact that they have not been invaded by dykes that have cut all the underlying formations.

On the Peak of Tristan similar thick trachybasalt lavas form the interfluves between the deeply eroded gulches. It is possible that an outpouring of trachybasalt lava could have been the closing phase of the main vent volcanicity on both islands.

4·2·7. *Surface parasitic centres*

On his geological sketch map of Inaccessible Dunne records the existence on the upper surface of the island of four cinder cones and describes the largest of these as being composed of red scoriaceous basalt intermixed with cinder. The composition of the other cones was not given. It is interesting to note that the largest cone, which measures some 325 yards across the rim, has its steepest slope to the west and is breached to the east. Although covered by denser vegetation, the surface cinder cones of Inaccessible are comparable in all respects to those on the Base of Tristan. On Tristan (p. 469) all breached cinder cones have the opening to the seaward side and their steepest slope facing the summit. By comparison, this could indicate that the main conduit of Inaccessible's primary volcano lay to the west of the present-day island.

These cinder cones were not examined by the writers but parts of them were seen from the sea and fleeting glimpses were obtained from the air. These observations generally confirm Dunne's account. The westward parts of the centres above Pig Beach and Salt Beach have been removed by erosion and the cliff sections display radially inclined red scoria and cinder.

5. Chemistry and petrogenesis

5·1. *Chemistry*

Chemical analyses and the normative compositions of rocks from the Tristan da Cunha group are listed in order of increasing Differentiation Index (Thornton & Tuttle 1960) in table 6 (after p. 520). Of the fifty-seven analyses listed, twenty-nine are of rocks collected by the Expedition. Seven of these analyses were made by Mr I. D. Bothwell of the Department of Mineralogy, British Museum (Natural History) and twenty-two by Mrs M. Kerr and Miss J. Baldwin of the Geology Department, University of Leeds. Of the remaining twenty-eight analyses, all except one are listed by Dunne (1941), twenty being his analyses.

The twenty-nine new chemical analyses are accompanied by spectrographic analyses of trace elements, made by Miss J. M. Rooke, Geology Department, University of Leeds. These spectrographic analyses are shown in table 7 (after p. 520). For comparison this table also shows the major element compositions, recalculated from percentages by weight of oxides to parts per thousand by weight of elements.

These element concentrations have been plotted in figures 13 to 17, as a function of a variation sequence. In most variation diagrams of this type, the sequence has been determined by the content of SiO_2, or the value ($\frac{1}{3}Si+K-Mg-Ca$) or the ratio $MgO/(MgO+FeO)$, or some variants of these. Although each of these give reasonably satisfactory classification of rocks into their probable differentiation sequence, the first two are empirical while the ratio $MgO/(MgO+FeO)$ is not suited for leucocratic volcanic rocks. The differentiation index (Thornton & Tuttle 1960), the percentage content of normative constituents in the residual system quartz-nepheline-kalsilite (i.e. normative *qtz*+*ab*+*or*+*ne*+*leu*+*ks*), does seem to have more theoretical validity. It is used here in preference to $\frac{1}{3}Si+K-Mg-Ca$ for this reason even though the latter has been used in plotting most trace element data for similar volcanic rocks so far (Nockolds & Allen 1953, 1954, 1956; Le Maitre 1962). Like all methods of arranging rocks in any sort of sequence of differentiation, it has limitations and many rocks appear aberrant. In practice, the Thornton–Tuttle index and the value $\frac{1}{3}Si+K-Mg-Ca$ gave very similar variation diagrams.

Tables 5 and 7.

TABLE 5. NAME, TYPE, LOCALITY, A

number	name	type	
114	ankaramite	lava	bas
62·1	olivine basalt	lava	Sar
6	alkali olivine basalt	neck	30(
64·4	trachybasalt	—	Tri
504	trachybasalt	dyke	Eas
64·3	trachybasalt	—	Tri
364	trachybasalt	lava	Ho
20	trachybasalt	block	sma
21	trachybasalt	lava	wes
369	trachybasalt	lava	nor
622	trachybasalt	lava	'Pi
64·2	doleritic olivine basalt	dyke	beh
117	flow-banded trachybasalt	lava	Sar
347	trachybasalt	lava	Pig
619	trachybasalt	bomb	insi
351	leucite-bearing trachybasalt	plug	10(
194	leucite-bearing trachybasalt	neck	Bli
125	leucite-bearing trachybasalt	lava	No
74·2	trachybasalt	lava	Fir
230	trachyandesite	lava	Sto
232	trachyandesite	spine	Sto
80·1	trachyandesite	lava	Fir
657	trachyandesite	bomb	196
518	trachyandesite	tholoid	196
617	trachyandesite	lava	196
572	porphyritic trachyandesite	lava	wes
627	trachyandesite	lava	196
80·5	trachyandesite	loose-block (lava)	Ca
560	plagioclase trachyte	plug	sou
86·3	sodalite plagioclase trachyte	plug	wit
30	phonolitic alkali feldspar trachyte	plug	40(
31	alkali feldspar trachyte	plug	10
86·5	sodalite trachyte	—	Sto
1713·4	'phonolitic tufa' (trachyandesite)	agglomerate	no
401	trachybasalt	dyke	cut
74·1	trachybasalt	dyke	Mi
74·3	trachybasalt	—	nor
74·4	trachybasalt	dyke	Mi
80·4	trachyandesite	—	eas
80·6	tephritic trachyte	—	Mi
412	trachyandesite	intrusive mass	20(
420	plagioclase trachyte	intrusive mass	nor
86·1	biotite trachyte	intrusive mass	Sto
439	alkali feldspar trachyte	lava	Ha
86·4	sodalite trachyte	—	eas
88·1	essexitic gabbro	dome	Ble
466	trachybasalt	dyke	He
64·1	olivine basalt	—	We
70·3	mugearite	dyke	So
70·1	mugearite	dyke	Ble
70·2	mugearite	vent	Ble
80·2	trachyandesite	thick flow	we
80·3	trachyandesite	thick flow	we
86·2	biotite trachyte	plug	cer

locality	analyst or reference
TRISTAN	
base of Main Cliffs; east end of Sandy Point	J. R. Baldwin (A)
Sandy Point	J. C. Dunne (1941, p. 62) (R & A)
300 yards west of Caves Gulch. 100 ft. O.D.	J. R. Baldwin (A)
Tristan	W. Campbell Smith (1930) (R)
East Molly Gulch. 4000 ft.	I. D. Bothwell (A)
Tristan	W. Campbell Smith (1930) (R)
Hottentot Gulch. 5400 ft. O.D.	J. R. Baldwin (A)
small cinder cone immediately north of Big Sandy Gulch	M. H. Kerr (A)
west headland of Boat Harbour Bay	M. H. Kerr (A)
north end of Stony Beach. 1800 ft. O.D.	M. H. Kerr (A)
'Pillow Lavas' foreshore immediately west of 1961 lava	M. H. Kerr (A)
behind Settlement	J. C. Dunne (1941, p. 64) (R & A)
Sandy Point, 100 yards north of East End Gulch	J. R. Baldwin (A)
Pigbite Gulch. 60 ft. O.D.	J. R. Baldwin (A)
inside crater wall, Frank's Hill	I. D. Bothwell (A)
100 yards east of summit crater lake. 6550 ft. O.D.	J. R. Baldwin (A)
Blineye parasitic centre	M. H. Kerr (A)
Noisy Beach, $\frac{3}{4}$ mile north of Lyon Point. 40 ft. O.D.	J. R. Baldwin (A)
First Lagoon Gulch	J. C. Dunne (1941, p. 74) (R & A)
Stony Hill; south-east lava	J. R. Baldwin (A)
Stony Hill; prominent spine near summit	J. R. Baldwin (A)
First Lagoon Gulch. 4000 ft. O.D.	J. C. Dunne (1941, p. 80) (R)
1961 eruption; glassy bomb, 100 yards west of tholoid	M. H. Kerr (A)
1961 eruption; west flank of tholoid, 40 yards from summit	M. H. Kerr (A)
1961 eruption; central flow	M. H. Kerr (A)
west side of Ridge-where-the-goat-jumped-off. 2500 ft. O.D.	I. D. Bothwell (A)
1961 eruption; north-east extremity of lava field	M. H. Kerr (A)
) Cave Gulch. 4550 ft. O.D.	J. C. Dunne (1941, p. 80) (R & A)
south-eastern flank of Peak	I. D. Bothwell (A)
within summit crater	J. C. Dunne (1941, p. 86) (R)
400 yards west of Settlement Quarry, foot of Main Cliffs	I. D. Bothwell (A)
10 yards east of specimen 30	I. D. Bothwell (A)
Stony Beach	J. C. Dunne (1941, p. 86) (R)
NIGHTINGALE	
north-east of Nightingale, opposite Middle Island	A. Renard (1889) (R)
cutting agglomerate north end of High Ridge	M. H. Kerr (A)
Middle Island	J. C. Dunne (1941, p. 74) (R)
north-east peak, Middle Island	W. Campbell Smith (1930) (R)
Middle Island	W. Campbell Smith (1930) (R)
eastern section, Nightingale Island	J. C. Dunne (1941, p. 80) (R)
Middle Island	W. Campbell Smith (1930) (R)
200 yards north-east of North Pond	M. H. Kerr (A)
north end of High Ridge	M. H. Kerr (A)
Stoltenhoff Island	J. C. Dunne (1941, p. 86) (R & A)
Hardies off Sea Hen Rocks	M. H. Kerr (A)
east side of Nightingale Island	J. C. Dunne (1941, p. 86) (R)
INACCESSIBLE	
Blenden Hall	J. C. Dunne (1941, p. 88) (R & A)
Headland, east of waterfall, Salt Beach	I. D. Bothwell (A)
West Point	J. C. Dunne (1941, p. 64) (R)
South Point	J. C. Dunne (1941, p. 70) (R & A)
Blenden Hall	W. Campbell Smith (1930) (R)
Blenden Hall	W. Campbell Smith (1930) (R)
western section above Blenden Hall	J. C. Dunne (1941, p. 80) (R & A)
western section above Blenden Hall	J. C. Dunne (1941, p. 80) (R & A)
central portion of Blenden Hall Dome	J. C. Dunne (1941, p. 86) (R & A)

TABLE 7. MAJOR ELEMENT CONTENT IN PARTS PER TH

specimen no.	114	6	504	364	20	21	369	622	117	347
Si	201	198	213	214	217	215	215	215	215	217
Ti	22	25	20	22	19	17	13	17	21	22
Al	64	75	97	88	88	90	89	90	94	85
Fe^{3+}	39	41	17	26	29	26	53	18	32	26
Fe^{2+}	64	66	65	57	57	58	42	65	48	54
Mn	1	—	—	—	—	—	—	—	—	—
Mg	62	40	28	29	28	29	29	28	25	28
Ca	90	85	71	71	67	68	67	67	69	68
Na	18	21	31	29	28	30	28	30	32	29
K	12	17	25	26	25	26	23	26	26	26
Fe (total)	103	107	82	83	86	84	95	83	80	80
differentiation index	22·6	27·9	39·7	41·8	43·0	43·0	43·1	43·3	43·7	45·0
Nb	20	35	100	110	120	130	95	130	85	110
Mo	< 3	3	4	5	6	6	5	7	5	6
Zr	100	200	300	300	350	350	300	350	300	300
Ga	25	27	27	28	28	28	27	35	27	27
Cr	250	65	—	—	30	45	18	30	—	—
V	400	400	200	400	190	180	200	200	200	300
Y	10	15	50	40	60	55	40	60	30	40
La	< 100	110	190	200	200	200	180	250	170	200
Be	—	—	—	—	—	—	—	—	—	—
Ni	150	50	—	—	—	10	—	10	—	—
Co	50	40	18	25	20	20	20	25	14	20
Mn	550	1100	1600	1600	1800	1800	1600	1700	1500	1500
Sr	700	1000	1200	1600	800	1100	1100	900	1100	1400
Pb	< 10	10	18	11	12	18	18	21	15	8
Ba	700	750	1000	1200	800	1000	950	850	950	1000
Li	< 4	4	10	7	4	4	< 4	6	10	7
Rb	90	110	300	170	180	170	110	170	110	160
(Ga/Al) × 10^3	0·39	0·36	0·28	0·32	0·32	0·31	0·30	0·39	0·29	0·32
(V/Mg) × 10^3	6·4	10	7·1	13·8	6·8	6·2	6·9	7·1	8	10·7
(Ni/Mg) × 10^3	2·4	1·2	—	—	—	0·4	—	0·4	—	—
(Co/Mg) × 10^3	0·8	1·0	0·6	0·9	0·7	0·7	0·7	0·9	0·6	0·7
Fe/Mg	1·66	2·7	2·9	2·9	3·1	2·9	3·3	3·0	3·2	2·9
(V/Fe) × 10^3	3·9	3·7	2·4	4·8	2·2	2·2	2·1	2·4	2·5	3·7
(Mn/Fe) × 10^3	5·3	10·3	20	19	21	22	17	21	19	19
(Y/Ca) × 10^3	—	0·2	0·7	0·6	0·9	0·8	0·6	0·9	0·4	0·6
(La/Ca) × 10^3	—	1·3	2·7	2·8	3·0	2·9	2·7	3·7	2·5	2·9
(Sr/Ca) × 10^3	7·8	12	17	23	12	16	16	13	16	21
(Ba/K) × 10^3	58	44	40	46	32	39	41	33	37	39
(Rb/K) × 10^3	7·5	6	12	7	7	7	5	7	4	6

PER THOUSAND OF METAL: SPECTROGRAPHIC ANALYSES OF TRACE ELEMENT CONTENT IN PARTS PER MIL

	Tristan															N	
	347	619	351	194	125	230	232	657	518	617	572	627	560	30	31	401	4
	217	216	220	227	231	252	253	257	255	256	253	256	271	279	284	227	2
	22	21	21	18	19	11	11	9	10	10	10	10	7	3	3	16	1
	85	96	92	95	94	101	103	104	102	101	106	105	103	104	108	94	9
	26	22	21	26	18	24	18	11	34	22	14	21	12	17	16	18	4
	54	52	52	40	44	24	26	26	9	23	26	21	17	16	3	40	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	-
	28	28	26	20	21	10	10	9	9	9	11	7	6	2	1	21	1
	68	67	64	61	54	45	44	41	41	40	37	40	24	9	10	58	2
	29	35	30	35	37	37	39	44	45	45	45	45	48	42	46	31	4
	26	27	28	28	32	38	38	42	41	41	46	43	44	55	56	27	4
	80	74	73	66	62	48	44	37	43	45	40	42	29	33	19	58	4
7	45·0	45·0	45·9	52·2	55·9	65·2	65·7	70·1	70·4	70·7	71·2	71·5	79·5	85·5	88·0	49·6	7
	110	100	80	160	120	160	160	140	170	150	130	140	130	160	230	130	14
	6	4	4	9	5	5	4	6	6	6	7	6	7	<3	4	5	
	300	300	300	400	350	350	400	350	350	350	300	350	350	500	500	350	50
	27	28	27	29	28	27	28	29	27	28	27	26	27	29	26	29	3
	—	—	—	—	17	—	12	—	—	—	—	—	—	—	—	—	1
	300	170	280	250	200	130	130	95	100	120	75	110	50	16	20	200	7
	40	45	25	50	40	45	50	40	55	45	45	45	35	20	40	40	3
	200	170	160	250	180	250	250	200	250	200	200	200	190	120	250	200	18
	—	—	—	—	—	—	—	—	—	—	—	—	—	8	13	—	-
	—	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
	20	18	15	14	10	—	—	—	—	—	—	—	—	—	—	12	1
	1500	1500	1300	1800	1400	1700	1700	1500	1800	1500	1300	1600	1200	1500	1900	1500	120
	1400	1100	1100	1100	1500	1200	1300	1300	1400	1500	1000	1400	650	40	55	1000	65
	8	35	10	16	10	17	15	14	16	17	22	14	28	24	25	16	1
	1000	950	1000	950	1200	1100	1100	1200	1300	1400	1100	1300	1000	20	25	950	70
	7	6	6	<4	10	12	11	10	12	13	12	13	15	15	20	8	
	160	180	110	220	190	200	200	230	220	210	270	260	350	400	280	150	22
29	0·32	0·29	0·28	0·31	0·30	0·27	0·27	0·28	0·27	0·28	0·25	0·25	0·26	0·28	0·24	0·31	
	10·7	6·1	10·8	12·5	9·5	13	13	10·6	11·1	13·3	6·8	16	8·3	8	20	9·5	
-	—	0·4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
6	0·7	0·6	0·6	0·7	0·5	—	—	—	—	—	—	—	—	—	—	0·6	
2	2·9	2·6	2·8	3·3	3·0	4·8	4·4	4·1	4·8	5·0	3·6	6	4·8	16	19	2·8	
5	3·7	2·3	3·8	3·8	2·9	2·7	3·0	2·6	2·3	2·7	1·9	2·6	1·7	0·5	1·1	3·4	
	19	20	18	37	23	35	39	41	42	33	32	38	41	45	160	26	2
4	0·6	0·7	0·4	0·8	0·7	1·0	1·1	1·0	1·3	1·1	1·2	1·1	1·5	2·2	4	0·7	
5	2·9	2·5	2·6	4·1	3·3	5·6	5·7	4·9	6·1	5·0	5·4	5·0	7·9	13	25	3·4	
	21	16	17	18	28	27	30	32	34	37	27	35	27	4	5	17	2
	39	35	36	34	38	29	29	29	32	34	24	30	23	0·4	0·4	35	1
	6	7	4	8	6	5	5	5	5	5	6	6	8	7	5	6	

PER MILLION

Nightingale				Inaccessible
401	412	420	439	466
227	268	271	291	217
16	10	7	2	16
94	90	95	108	94
18	45	20	2	23
40	2	18	7	56
—	—	—	—	—
21	12	7	0	35
58	27	23	9	66
31	40	45	44	29
27	43	50	59	22
58	47	38	9	79
49·6	76·1	81·0	90·3	39·3
130	140	140	130	110
5	6	10	3	5
350	500	550	550	300
29	35	35	30	24
—	17	16	—	20
200	75	75	10	200
40	35	15	10	50
200	180	<100	100	180
—	—	—	—	—
—	45	—	—	80
12	10	—	—	—
500	1200	1000	650	1600
000	650	750	180	800
16	14	17	18	32
950	700	700	160	850
8	8	15	9	8
150	220	270	250	170
0·31	0·39	0·37	0·28	0·26
9·5	6·2	10·7	—	5·7
—	3·7	—	—	2·3
0·6	0·8	—	—	1·0
2·8	3·9	5·4	—	2·3
3·4	1·6	2·0	1·1	2·5
26	25	26	72	20
0·7	1·3	0·7	1·1	0·8
3·4	6·7	—	11·0	2·7
17	24	33	20	12
35	16	14	3	39
6	5	5	4	8

80·3	trachyandesite	thick flow	we
86·2	biotite trachyte	plug	ce

(*After p.* 520)

western section above Blenden Hall	J. C. Dunne (1941, p. 80) (R & A)
central portion of Blenden Hall Dome	J. C. Dunne (1941, p. 86) (R & A)

	ankaramites		olivine basalt							
specimen no.	114*	62·1	6*	64·4	504*	64·3	364*	20*	21*	3(
SiO_2	42·93	42·51	42·43	46·31	45·5	47·44	45·70	46·48	46·00	46
TiO_2	3·73	4·29	4·11	3·64	3·3	4·02	3·65	3·10	2·83	2
Al_2O_3	12·05	12·82	14·15	17·36	18·3	17·17	16·70	16·68	17·03	16
Fe_2O_3	5·58	4·89	5·84	3·27	2·5	3·10	3·73	4·12	3·79	7
FeO	8·27	8·64	8·48	8·12	8·4	7·07	7·28	7·30	7·47	5
MnO	0·16	0·13	0·17	0·17	0·1	0·14	0·17	0·18	0·23	0
MgO	10·28	9·63	6·71	4·64	4·6	4·65	4·89	4·65	4·80	4
CaO	12·58	12·22	11·91	9·74	10·0	9·78	9·91	9·40	9·54	9
Na_2O	2·36	2·83	2·77	3·67	4·2	3·71	3·96	3·80	4·04	3
K_2O	1·47	1·40	2·04	2·79	3·0	2·95	3·10	3·07	3·11	2
H_2O+	0·15	0·41	0·34	0·21	0·1	0·28	0·09	0·57	0·09	(
H_2O-	0·11	0·05	0·44	0·08	0·2	0·11	0·12	0·07	0·02	(
P_2O_5	0·59	0·38	0·58	0·00	0·3	0·00	0·84	0·90	1·06	1
Cl	—	—	—	—	—	—	—	—	—	-
F	—	—	—	—	—	—	—	—	—	-
ZrO_2	—	—	—	—	—	—	—	—	—	-
	100·26	100·20	99·97	100·00	100·5	100·42	100·14	100·32	100·01	10(
analyst	J.R.B.		J.R.B.		I.D.B.		J.R.B.	M.H.K.	M.H.K.	M.I
Q	—	—	—	—	—	—	—	—	—	-
C	—	—	—	—	—	—	—	—	—	-
Z	—	—	—	—	—	—	—	—	—	-
or	8·68	8·28	12·06	16·49	17·73	17·74	18·32	18·15	18·38	1(
ab	6·73	5·58	6·95	11·94	6·03	14·24	11·58	16·16	13·27	2
an	17·95	18·15	20·16	22·66	22·23	21·49	18·64	19·39	19·15	2
leu	—	—	—	—	—	—	—	—	—	-
ne	7·17	9·95	8·93	10·36	15·99	9·29	11·88	8·66	11·33	5
di	32·18	31·76	28·01	20·85	20·80	21·69	20·12	17·25	17·24	1
ol	10·76	9·92	5·48	5·77	6·84	3·76	5·11	6·12	7·21	4
hy	—	—	—	—	—	—	—	—	—	-
wo	—	—	—	—	—	—	—	—	—	-
mt	8·09	7·09	8·47	4·74	3·63	4·49	5·41	5·97	5·49	1
il	7·08	8·15	7·81	6·91	6·27	7·63	6·93	5·89	5·37	4
hm	—	—	—	—	—	—	—	—	—	-
ap	1·39	0·90	1·37	—	0·71	—	1·98	2·12	2·50	2
fr	—	—	—	—	—	—	—	—	—	-
hl	—	—	—	—	—	—	—	—	—	-
H_2O+	0·13	0·39	0·32	0·21	0·09	0·28	0·05	0·53	0·05	(
H_2O-	0·11	0·05	0·44	0·08	0·20	0·11	0·12	0·07	0·02	(
pf	—	—	—	—	—	—	—	—	—	-
ru	—	—	—	—	—	—	—	—	—	-
tn	—	—	—	—	—	—	—	—	—	-
	100·27	100·22	100·00	100·01	100·52	100·42	100·14	100·31	100·01	10(
$\frac{FeO}{MgO+FeO}$ % in *di*, *ol*, *hy*	12·3	13·7	16·3	30·0	35·0	21·0	22·2	25·5	28·8	1
differentiation index	22·6	23·8	27·9	38·8	39·7	41·0	41·8	43·0	43·0	4

	Tristan											
	trachybasalts											
	369*	622*	64·2	117*	347*	619*	351*	194*	125*	74·2	230*	232
)	46·01	46·07	46·24	45·96	46·36	46·2	47·06	48·54	49·52	50·02	53·90	54·
3	2·19	3·08	4·48	3·44	3·54	3·5	3·44	2·98	3·18	3·39	1·77	1·
3	16·84	17·06	15·75	17·84	16·19	18·1	17·14	18·00	17·72	19·58	19·00	19·
)	7·61	2·59	3·04	4·53	3·66	3·1	3·29	3·78	2·55	2·29	3·37	2·
7	5·37	8·32	7·39	6·21	6·94	6·7	6·65	5·18	5·66	5·24	3·05	3·
3	0·18	0·18	0·14	0·20	0·18	0·2	0·18	0·18	0·18	0·12	0·18	0·
)	4·75	4·72	4·92	4·13	4·57	4·6	4·35	3·32	3·42	3·15	1·68	1·
4	9·36	9·35	9·57	9·61	9·45	9·4	9·00	8·49	7·58	6·32	6·25	6·
4	3·74	4·01	4·12	4·27	3·97	4·7	4·08	4·74	4·94	5·15	5·04	5·
1	2·72	3·16	2·60	3·16	3·15	3·3	3·40	3·38	3·88	3·71	4·53	4·
)	0·01	0·12	0·29	0·17	0·29	0·2	0·37	0·14	0·29	0·21	0·19	0·
2	0·08	0·06	0·05	0·05	0·19	tr.	0·27	0·03	0·15	0·00	0·28	0·
6	1·18	1·22	1·20	0·52	1·42	0·5	0·75	1·18	1·09	1·02	0·74	0·
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
1	100·04	99·94	99·79	100·09	99·91	100·5	99·98	99·94	100·16	100·20	99·98	100·
K.	M.H.K.	M.H.K.		J.R.B.	J.R.B.	I.D.B.	J.R.B.	M.H.K.	J.R.B.		J.R.B.	J.R.
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
8	16·08	18·68	15·37	18·68	18·62	19·51	20·10	19·98	22·93	21·93	26·78	26·
7	21·63	13·63	19·82	11·88	17·92	8·70	15·45	22·80	22·48	28·06	33·37	32·
5	21·13	19·22	16·81	20·18	17·06	18·55	18·42	17·86	14·72	19·36	15·85	16·
	—	—	—	—	—	—	—	—	—	—	—	—
3	5·43	10·99	8·15	13·13	8·49	16·83	10·33	9·37	10·46	8·40	5·02	6·
4	13·73	15·71	18·28	19·16	16·51	19·95	17·15	13·15	12·68	4·26	8·09	7·
1	4·03	9·09	5·33	2·53	5·51	4·47	4·85	2·73	4·17	5·86	0·45	1·
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
9	11·03	3·76	4·41	6·57	5·31	4·49	4·77	5·48	3·70	3·32	4·89	3·
7	4·16	5·85	8·51	6·53	6·72	6·65	6·53	5·65	6·04	6·44	3·36	3·
	—	—	—	—	—	—	—	—	—	—	—	—
0	2·78	2·88	2·81	1·23	3·35	1·18	1·77	2·78	2·51	2·41	1·75	1·
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
5	0·04	0·07	0·24	0·15	0·23	0·18	0·34	0·09	0·24	0·17	0·16	0·
2	0·08	0·06	0·05	0·05	0·19	—	0·27	0·03	0·15	—	0·28	0·
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
1	100·04	99·94	99·80	100·09	99·92	100·52	99·98	99·92	100·15	100·21	100·00	100·
	1·8	35·2	19·6	14·8	22·0	22·4	22·6	14·2	23·1	18·6	4·0	20·
	43·1	43·3	43·3	43·7	45·0	45·0	45·9	52·2	55·9	58·4	65·2	65·

TABLE 6. ROCK ANALYSES (* indicates new analysis)

	trachyandesites								trachytes			
*	232*	80·1	657*	518*	617*	572*	627*	80·5	560*	86·3	30*	31*
0	54·04	54·43	54·95	54·53	54·76	54·1	54·66	54·35	58·0	58·20	59·6	60·
7	1·81	1·82	1·58	1·62	1·62	1·7	1·60	2·18	1·2	1·33	0·5	0·
0	19·54	18·23	19·63	19·35	19·06	20·0	19·91	19·97	19·5	19·10	19·6	20·
7	2·60	3·24	1·62	4·85	3·15	2·0	3·07	1·52	1·7	2·24	2·4	2·
5	3·35	2·66	3·31	1·20	2·95	3·3	2·73	3·15	2·2	1·28	0·1	0·
8	0·19	0·09	0·18	0·18	0·18	0·2	0·18	0·24	0·1	0·08	0·2	0·
8	1·66	1·52	1·42	1·50	1·51	1·8	1·10	1·35	1·0	0·81	0·4	0·
5	6·22	5·83	5·73	5·76	5·60	5·2	5·56	4·52	3·3	3·58	1·3	1·
4	5·26	5·64	5·89	5·84	5·87	6·1	5·85	6·71	6·5	6·30	5·7	6·
3	4·53	4·71	4·95	4·83	4·89	5·6	5·03	4·53	5·3	5·94	6·6	6·
9	0·11	1·55	0·00	0·00	0·03	0·2	0·00	0·38	0·2	0·90	2·3	1·
8	0·19	0·00	0·01	0·02	0·03	0·3	0·00	0·04	0·1	0·13	1·3	0·
4	0·75	0·42	0·43	0·38	0·36	0·3	0·29	0·89	0·2	0·21	0·05	0·
	—	—	0·27	0·11	0·13	—	0·23	—	—	0·06	—	—
	—	—	0·08	0·12	0·10	—	0·10	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
8	100·25	100·14	99·96†	100·22†	100·17†	100·8	100·22†	99·83	99·3	100·16	100·05	100·
.	J.R.B.		M.H.K.	M.H.K.	M.H.K.	I.D.B.	M.H.K.		I.D.B.		I.D.B.	I.D.

NORMS

	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	0·84	0·
	—	—	—	—	—	—	—	—	—	—	—	—
8	26·78	27·84	29·27	28·55	28·88	33·10	29·72	26·78	31·33	35·11	39·01	39·
7	32·25	33·33	29·99	31·61	31·67	22·20	31·14	35·16	40·12	37·51	44·39	43·
5	16·33	10·52	13·57	12·68	11·74	10·66	14·10	11·00	8·38	6·53	6·12	6·
	—	—	—	—	—	—	—	—	—	—	—	—
2	6·64	7·80	9·66	9·26	9·23	15·94	9·03	11·71	8·06	8·32	2·08	4·
9	7·71	8·17	9·60	8·03	8·96	10·64	6·22	4·52	5·36	4·35	—	—
5	1·30	—	0·94	—	—	0·96	—	1·85	0·55	—	0·70	0·
	—	—	—	—	—	—	—	—	—	—	—	—
	—	2·16	—	0·88	0·77	—	1·29	—	—	1·78	—	—
9	3·77	3·59	2·34	—	4·56	2·90	4·45	2·20	2·46	0·53	—	0·
6	3·44	3·46	3·00	2·91	3·08	3·23	3·03	4·14	2·28	2·53	0·64	0·
	—	0·76	—	4·85	—	—	—	—	—	1·87	2·40	1·
5	1·77	0·99	1·01	0·91	0·84	0·71	0·67	2·10	0·47	0·50	0·12	0·
	—	—	0·09	0·17	0·14	—	0·16	—	—	—	—	—
	—	—	0·45	0·18	0·21	—	0·37	—	—	0·10	—	—
6	0·08	1·53	0·02	0·02	0·03	0·19	0·00	0·34	0·19	—	2·30	1·
8	0·19	—	—	0·02	0·03	0·30	0·00	0·04	0·10	—	1·30	0·
	—	—	—	0·12	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	0·16	—
	—	—	—	—	—	—	—	—	—	—	—	—
0	100·25	100·15	99·93	100·17	100·14	100·83	100·18	99·84	99·30	100·13	100·06	100·
	20·1	0	34·7	0	8·8	25·1	4·5	23·7	20·4	0	0	0
	65·7	69·0	70·1	70·4	70·7	71·2	71·5	73·6	79·5	80·9	85·5	88·

† Corrected for O≡F, Cl.

			Nightingale									
	...es		trachybasalts					trachyandesites				
	31*	86·5	1713·4	401*	74·1	74·3	74·4	80·4	80·6	412*	420*	86·
	60·7	58·71	48·09	48·59	48·76	50·64	52·13	54·40	57·10	57·31	58·07	59·
	0·5	0·39	4·38	2·61	2·93	2·50	2·00	2·38	1·11	1·59	1·25	1·
	20·5	20·03	19·05	17·78	15·10	21·75	20·48	17·34	21·05	17·01	18·01	18·
	2·3	2·16	3·44	2·64	4·23	0·19	3·81	3·04	1·76	6·47	2·92	2·
	0·4	0·45	5·59	5·12	5·27	5·93	2·20	3·69	2·01	0·28	2·30	1·
	0·2	0·10	0·00	0·17	0·07	0·07	0·07	0·07	0·11	0·12	0·13	0·
	0·2	0·00	3·50	3·53	3·54	2·56	1·96	2·50	1·20	2·05	1·15	0·
	1·4	0·98	9·42	8·08	7·45	6·88	5·55	4·94	4·13	3·71	3·15	2·
	6·2	7·56	5·06	4·13	4·43	5·27	3·92	5·11	5·01	5·38	6·00	6·
	6·7	6·03	2·88	3·27	3·96	3·73	3·75	4·73	5·33	5·17	6·02	5·
	1·0	3·19	0·67	1·86	3·11	0·44	2·21	1·11	0·97	0·10	0·28	0·
	0·4	0·22	0·00	1·30	0·43	0·31	1·96	0·00	0·43	0·28	0·38	0·
5	0·03	0·06	0·00	0·87	0·83	0·00	0·00	0·69	0·00	0·52	0·43	0·
	—	0·32	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	0·10	—	—	—	—
5	100·53	100·13	102·08	99·95	100·11	100·27	100·04	100·10	100·21	99·99	100·09	99·
.	I.D.B.			M.H.K.						M.H.K.	M.H.K.	
	—	—	—	—	—	—	0·23	—	—	—	—	—
4	0·58	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	0·15	—	—	—	—
1	39·60	35·64	17·02	19·33	23·41	22·05	22·16	27·96	31·50	30·55	35·58	34·
9	43·57	42·87	16·09	24·79	23·52	19·59	33·17	36·58	37·61	45·52	39·17	44·
2	6·75	4·17	20·77	20·32	9·63	24·68	27·22	10·41	19·21	7·00	4·44	5·
	—	—	—	—	—	—	—	—	—	—	—	—
8	4·82	10·15	14·48	5·50	7·56	13·54	—	3·61	2·59	—	6·28	3·
	—	—	19·16	11·31	17·34	7·84	0·25	7·52	1·01	3·13	6·18	4·
0	0·35	—	—	4·74	1·49	6·80	—	2·24	2·22	2·56	—	0·
	—	—	—	—	—	—	4·77	—	—	—	—	—
	—	0·12	0·59	—	—	—	—	—	—	—	0·19	—
	0·49	0·65	5·00	3·83	6·13	0·28	1·52	4·41	2·55	—	4·21	0·
4	0·95	0·74	8·32	4·96	5·56	4·75	3·80	4·52	2·11	0·85	2·37	2·
0	1·96	1·71	—	—	—	—	2·76	—	—	6·47	0·01	2·
2	0·07	0·14	—	2·05	1·96	—	—	1·63	—	1·23	1·01	0·
	—	—	—	—	—	—	—	—	—	—	—	—
	—	0·53	—	—	—	—	—	—	—	—	—	—
0	1·00	3·19	0·67	1·82	3·08	0·44	2·21	1·08	0·97	0·08	0·26	0·
0	0·40	0·22	—	1·30	0·43	0·31	1·96	—	0·43	1·28	0·38	0·
	—	—	—	—	—	—	—	—	—	1·11	—	—
6	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	1·21	—	—
6	100·54	100·13	102·10	99·95	100·12	100·28	100·05	100·11	100·20	99·99	100·08	99·
	0	100	1·6	21·8	11·3	44·6	0	5·4	13·4	0	0	0
	88·0	88·7	47·6	49·6	54·5	55·2	55·6	68·1	71·7	76·1	81·0	82

				Inaccessible								
	trachytes			olivine basalt	trachybasalts					trachyandesites		trach
	86·1	439*	86·4	88·1	466*	64·1	70·3	70·1	70·2	80·2	80·3	86
7	59·91	62·50	62·23	48·11	46·4	47·76	49·30	49·30	48·10	55·51	54·94	62·
5	1·21	0·38	0·65	3·27	2·6	3·05	3·18	2·02	2·60	2·12	2·18	0·
1	18·44	20·39	18·43	14·29	17·7	15·68	16·36	18·85	19·39	18·20	17·69	18·
2	2·88	0·31	1·68	2·01	3·3	3·34	3·69	4·37	8·02	3·04	2·97	1·
0	1·20	0·84	0·60	7·63	7·2	6·55	5·94	5·80	3·03	4·03	3·29	0·
3	0·07	0·09	0·12	0·15	0·2	0·07	0·16	tr.	0·13	0·13	0·12	0·
5	0·97	0·02	0·11	10·13	5·8	6·05	5·31	3·95	2·91	2·05	2·87	0·
5	2·73	1·28	1·16	9·71	9·3	9·02	7·40	7·66	4·61	4·67	4·73	1·
0	6·05	5·93	6·77	2·92	3·9	4·22	4·09	3·89	4·81	5·43	5·05	6·
2	5·83	7·08	6·28	0·98	2·6	1·94	1·71	2·65	2·56	3·15	3·76	5·
3	0·30	0·64	1·60	0·46	0·8	1·87	1·67	0·45	1·87	0·56	1·03	0·
8	0·16	0·69	0·06	0·09	0·9	0·00	0·49	0·30	2·08	0·25	0·47	0·
3	0·22	0·10	0·07	0·31	0·2	0·49	0·49	0·64	0·00	0·56	0·62	0·
	—	—	0·32	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
9	99·97	100·25	100·01	100·06	100·9	100·04	99·79	99·88	100·11	99·70	99·72	99·
K.		M.H.K.			I.D.B.							
	—	—	—	—	—	—	—	—	—	0·40	—	2·
	—	0·89	—	—	—	—	—	—	0·33	—	—	0·
	—	—	—	—	—	—	—	—	—	—	—	—
8	34·46	41·85	37·12	5·79	15·37	11·47	10·11	15·66	15·13	18·62	22·22	29·
7	44·90	46·34	51·79	24·71	13·19	24·51	34·61	30·65	36·93	45·94	42·73	53·
4	5·95	5·70	2·61	23·00	23·12	18·11	21·24	26·65	22·87	15·99	14·50	7·
	—	—	—	—	—	—	—	—	—	—	—	—
8	3·41	2·08	1·69	—	10·73	6·07	—	1·23	2·04	—	—	—
8	4·80	—	0·59	18·49	17·54	18·72	9·76	6·16	—	2·82	3·84	—
	0·14	0·67	—	15·05	9·07	7·52	5·23	7·62	5·08	—	1·24	—
	—	—	—	2·63	—	—	4·18	—	—	5·39	3·81	1·
9	—	—	0·80	—	—	—	—	—	—	—	—	-
1	0·59	0·44	0·44	2·91	4·78	4·84	5·35	6·34	2·65	4·41	4·31	0·
7	2·30	0·72	1·23	6·21	4·94	5·79	6·04	3·84	4·94	4·03	4·14	1·
1	2·47	—	1·38	—	—	—	—	—	6·19	—	—	1·
1	0·52	0·24	0·17	0·73	0·47	1·16	1·16	1·51	—	1·32	1·46	0·
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	0·53	—	—	—	—	—	—	—	—	—
6	0·29	0·64	1·60	0·45	0·79	1·85	1·65	0·42	1·87	0·54	1·00	0·
8	0·16	0·69	0·06	0·09	0·90	—	0·49	0·32	2·08	0·25	0·47	0·
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
8	99·99	100·26	100·01	100·06	100·9	100·04	99·82	99·88	100·11	99·71	99·73	99·
	0	92·7	0	17·9	25·7	18·1	14·3	22·3	0	19·5	2·2	0
0	82·8	90·3	90·6	30·5	39·3	42·0	44·7	47·5	54·1	65·0	65·0	85·

Table 6.

s	trachyte	
3	86·2	specimen no.
4	62·36	SiO_2
8	0·72	TiO_2
9	18·99	Al_2O_3
7	1·76	Fe_2O_3
9	0·87	FeO
2	0·04	MnO
7	0·78	MgO
3	1·78	CaO
5	6·30	Na_2O
6	5·01	K_2O
3	0·63	H_2O+
7	0·24	H_2O-
2	0·21	P_2O_5
	—	Cl
	—	F
	—	ZrO_2
2	99·69	
		analyst
	2·16	*Q*
	0·47	*C*
	—	*Z*
2	29·61	*or*
3	53·30	*ab*
0	7·46	*an*
	—	*leu*
	—	*ne*
4	—	*di*
4	—	*ol*
1	1·94	*hy*
	—	*wo*
1	0·85	*mt*
4	1·37	*il*
	1·18	*hm*
6	0·50	*ap*
	—	*fr*
	—	*hl*
0	0·62	H_2O+
7	0·24	H_2O-
	—	*pf*
	—	*ru*
	—	*tn*
3	99·70	
	0	$\frac{FeO}{MgO+FeO}$ % in *di, ol, hy*
	85·1	differentiation index

(*Facing Tables* 5 *and* 7)

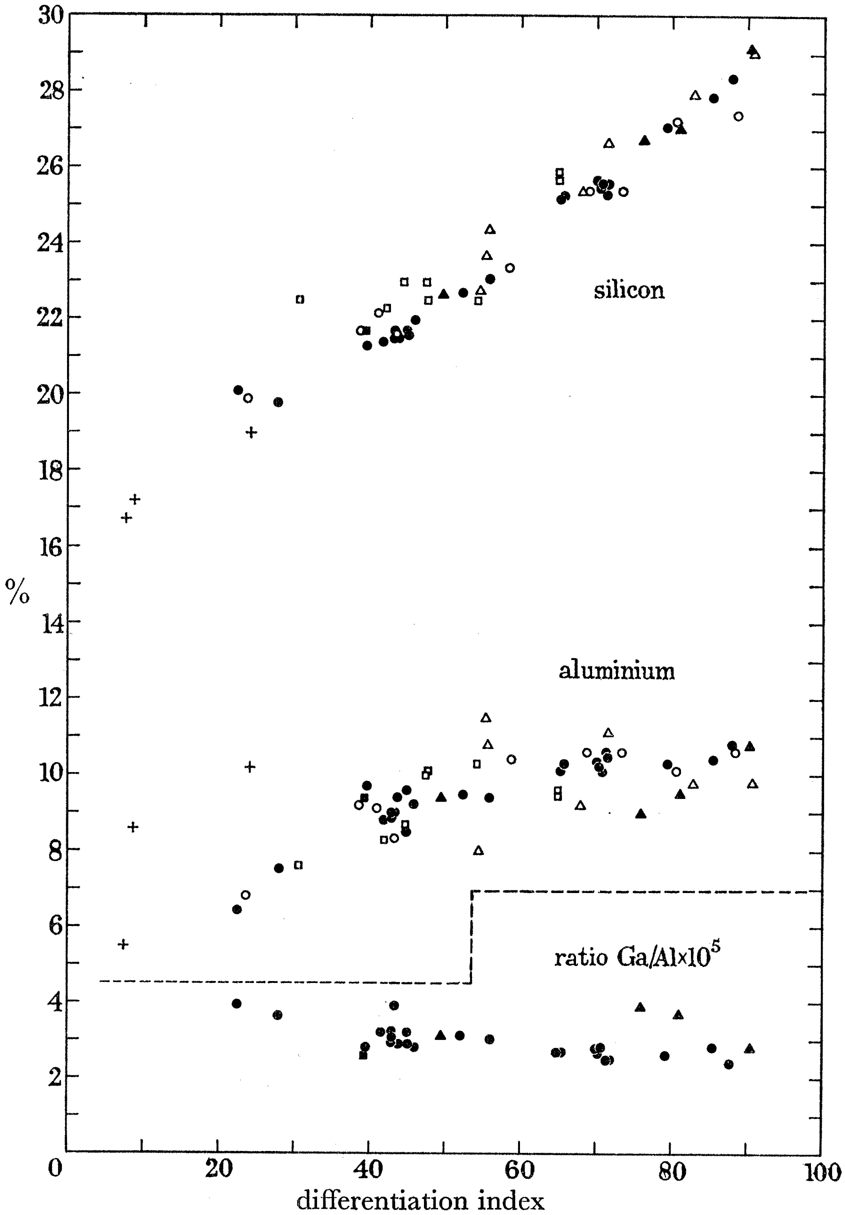

FIGURE 13. Si, Al, Ga/Al × 10^5.

	new analysis	previous analysis	
Tristan	●	○	
Nightingale	▲	△	analysis of xenolith +
Inaccessible	■	□	

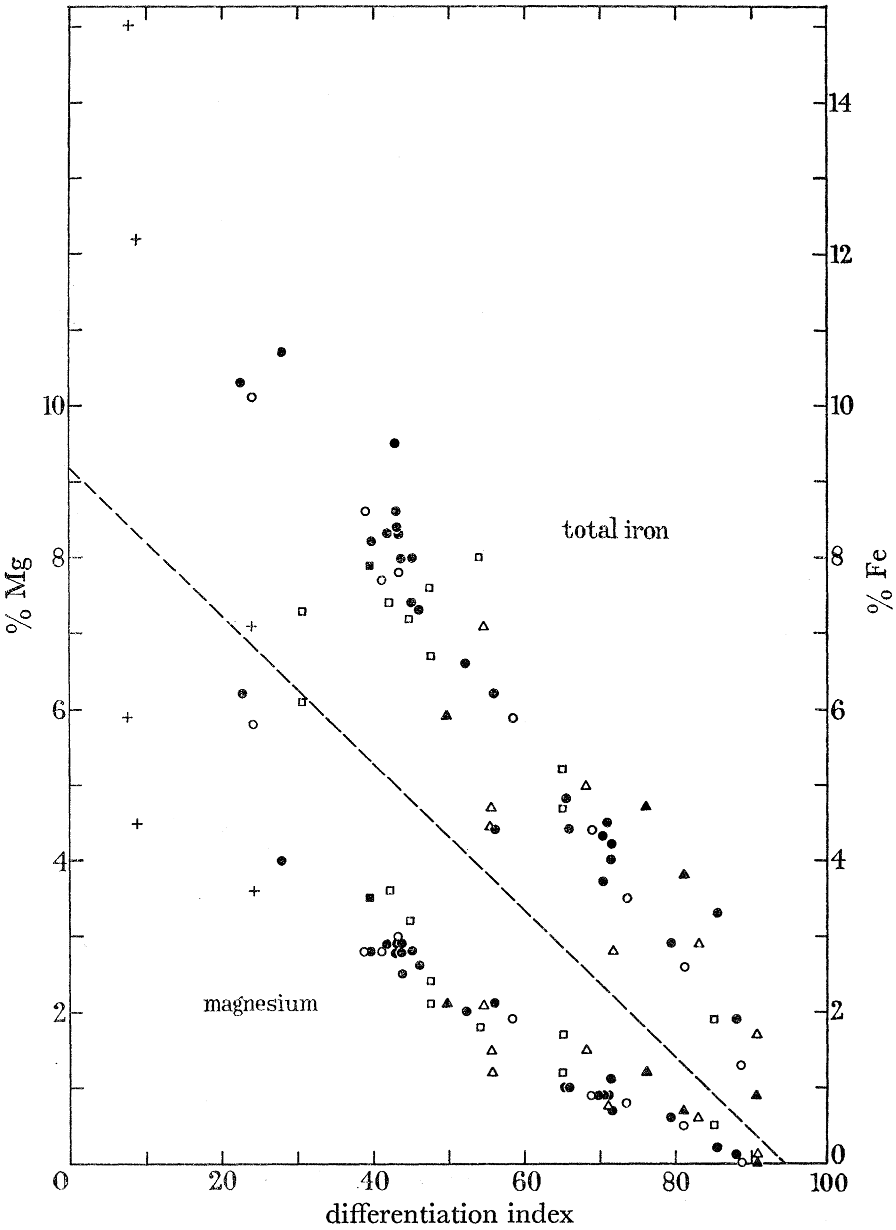

FIGURE 14. Total Fe and Mg.

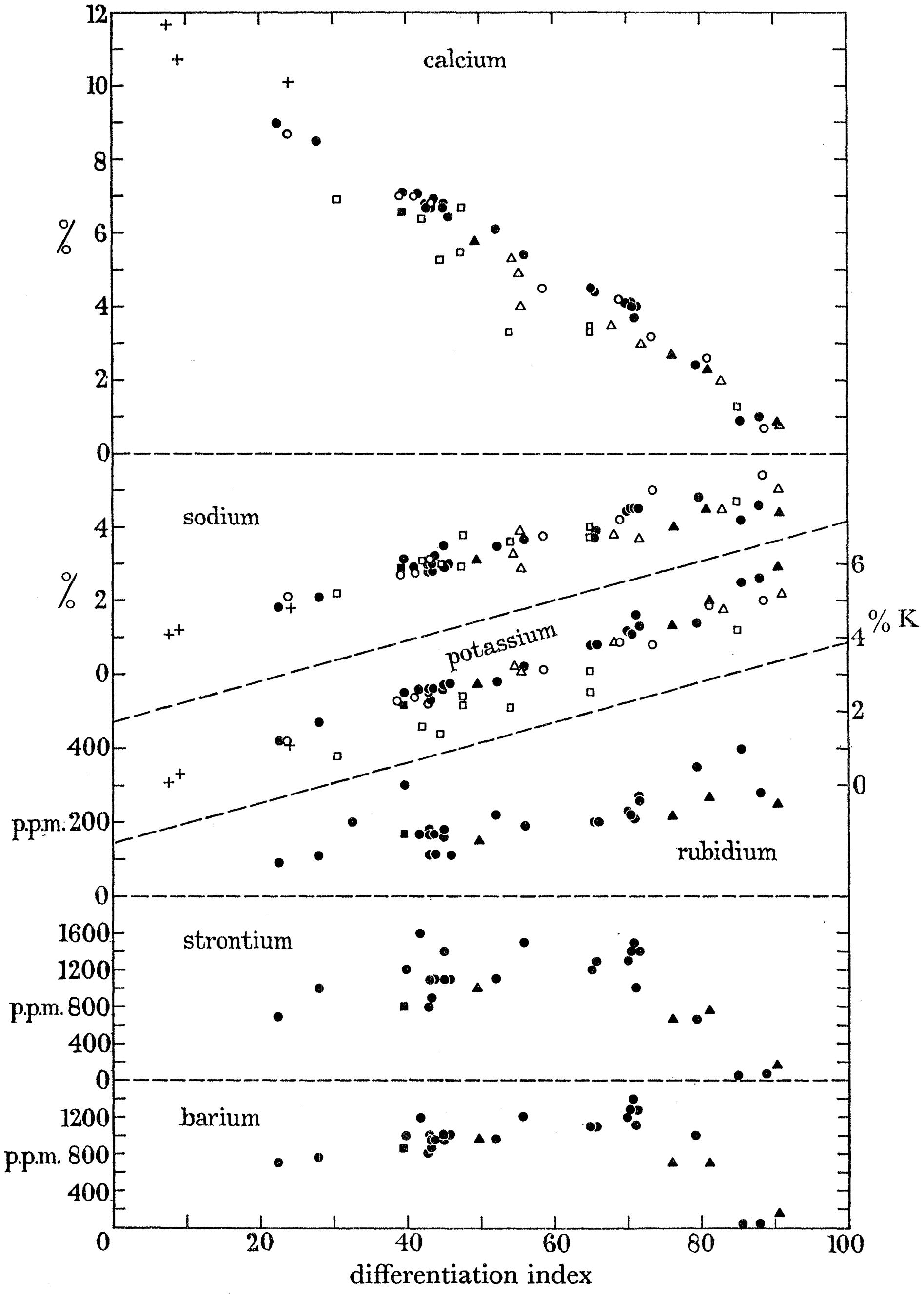

FIGURE 15. Ca, Na, K, Rb, Sr, Ba.

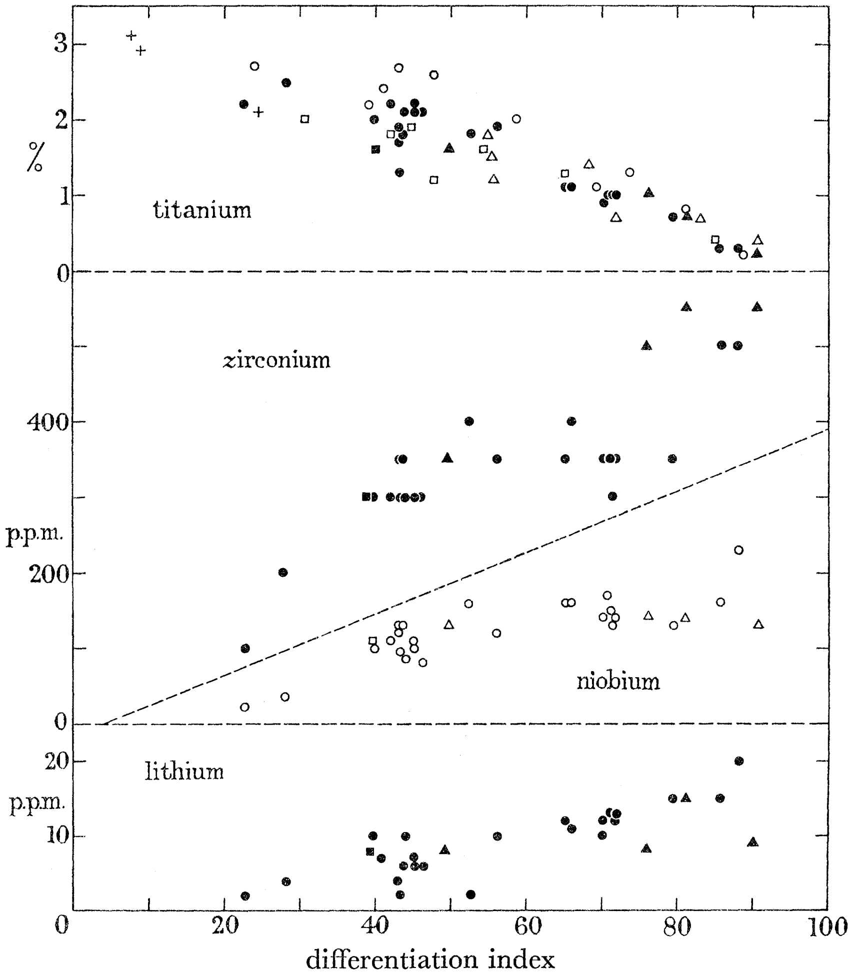

FIGURE 16. Ti, Zr, Nb, Li.
(Niobium all new analyses.)

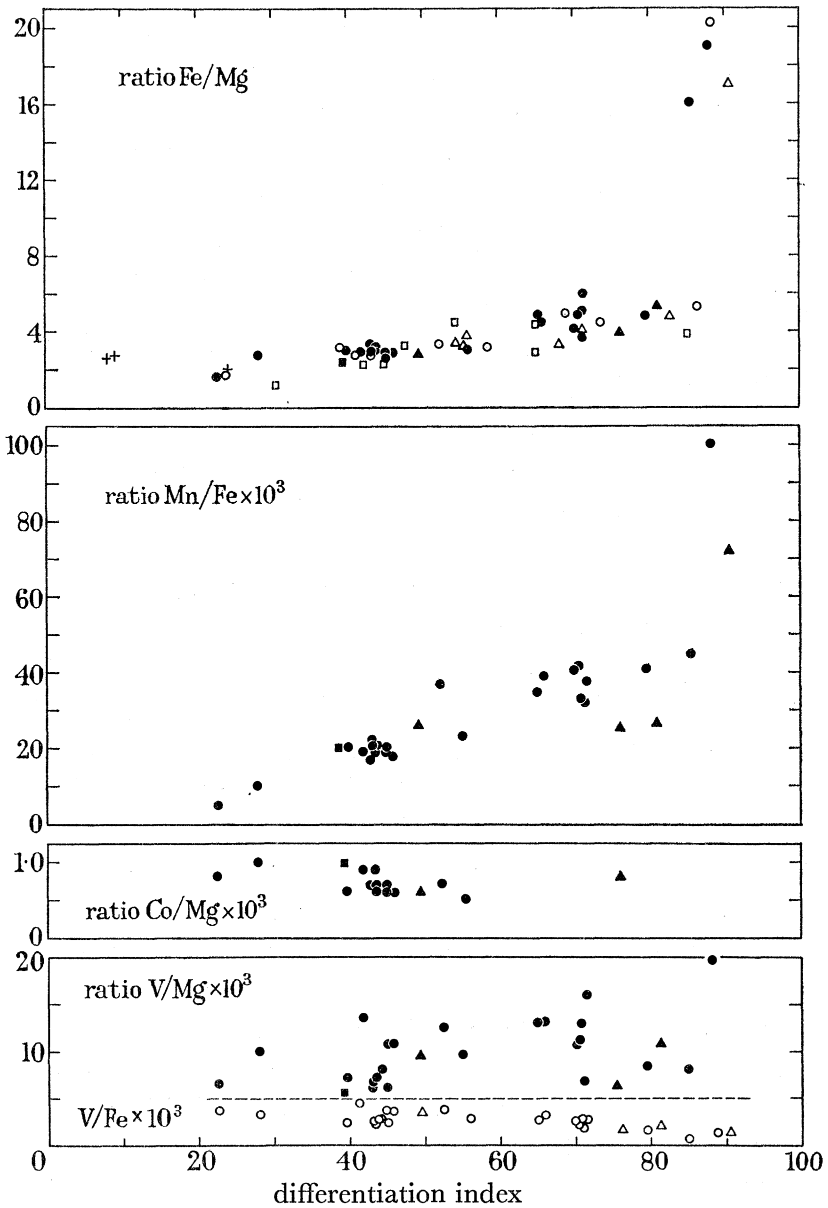

FIGURE 17. Mg/Fe, Mn/Fe × 10^3, Co/Mg × 10^3, V/Mg × 10^3, V/Fe × 10^3. (Vanadium all new analyses.)

It will be noted from the diagrams that inclusion of previous analyses leads to greater scatter of the points. Despite this, it was considered desirable to include all previous analyses.

In plotting the diagrams and in discussing them, it is implied that the rocks form part of a differentiation sequence, the successive members being the result of some sort of differentiation processes. The validity of this is discussed later.

Silicon. The curve for silicon (figure 13) is relatively smooth, and the points show less deviation than for the other elements. This is a common experience and could be expected. Since the abundant minerals are silicates, an abnormal behaviour or concentration of one mineral will affect the content of silicon less than that of any other element except oxygen.

The chief deviant points are those for rocks from Inaccessible and Nightingale. Curves for other elements also indicate that the rocks from the three islands are not part of a single variation sequence, but that there appear to be differences between the rock assemblages from the three islands.

Aluminium. Aluminium (figure 13) shows a rapid increase from the accumulate rocks (ankaramites) to the basalts. Thereafter, the increase is gradual and somewhat irregular. In this increase the Tristan rocks resemble the Polynesian alkaline suite (Nockolds & Allan 1954).

Gallium. The gallium content remains fairly constant throughout the sequence except for the few specimens from Nightingale and Inaccessible. However, the Ga/Al ratio (figure 13) does show a definite decrease due to the increase in aluminium.

This change, similar to that found in the Polynesian alkali-basalt province, differs from that of other alkali provinces (Nockolds & Allan 1954) and even from that of the neighbouring island of Gough (Le Maitre 1962). In these cases the ratio is either unchanged or increases towards the feldspathic end.

The two most basic rocks from Tristan have an anomalously high Ga/Al ratio because of their low aluminium content. In these it is probable that gallium has substituted for ferric ions in ferromagnesian minerals, or has preferentially replaced 6-co-ordinated aluminium in pyroxene.

Magnesium and iron. Magnesium (figure 14) diminishes steadily during differentiation reaching a very low value (0·02 %) in one trachyte. In this respect, alkaline rocks resemble calc-alkaline ones where in pitchstones and residual glasses MgO can fall below 0·01 %.

Iron also decreases steadily, though less rapidly than Mg so that the ratio Fe/Mg increases, especially towards the end of the series when it reaches very high values.

The values for total Fe are rather more regular than those for Fe^{2+}, probably due to the effect of oxidation on the latter.

Vanadium. Vanadium decreases with differentiation, the degree of removal being about parallel to that of iron. The ratio V/Mg (figure 17), though irregular, does show a general increase while the ratio V/Fe (figure 17) is relatively constant.

Nickel, cobalt and chromium. Nickel could be detected only in the most basic samples, and even here was not abundant. In this it contrasts with the rocks from Gough Island (Le Maitre 1962). Chromium behaves in the same way. Cobalt was more abundant in many samples, a feature common in many volcanic series (Nockolds & Allan 1954). The Co/Mg was relatively constant over the limit of estimation of cobalt.

Manganese. The manganese content remained relatively uniform throughout. The Mn/Fe ratio increased markedly with differentiation, due to decrease in Fe content.

Yttrium and lanthanum. Both yttrium and lanthanum remained relatively constant in value throughout the series, showing no increase towards the felsic end. Both appear to be more abundant than in other volcanic suites (e.g. Le Maitre 1962; Nockolds & Allan 1953, 1954, 1956).

Calcium, strontium and barium. Calcium shows a regular decrease throughout (figure 15). Strontium builds up to a maximum in the intermediate rocks and then falls rapidly in the final trachytic members. Barium behaves in an almost identical manner. The lack of correlation between the behaviour of strontium and the appearance of calcium minerals indicates that strontium is not replacing calcium preferentially, presumably the Sr/Ca ratio of the minerals being lower than that of the liquid. It is not until alkali feldspar appears as phenocrysts that strontium and barium are preferentially removed, and their concentrations markedly reduced. Strontium and barium would be expected to enter the leucite which appears even in the more basic rocks. The fact that the differentiation behaviour of strontium and barium shows no early removal indicates that leucite played no part in the differentiation at depth. This is in accordance with the petrographic observations and deductions on the nature and history of the leucite.

The contents of both strontium and barium are high for the average basaltic province but resemble those of some of the alkali basaltic provinces described by Nockolds & Allan (1954). They are slightly higher than those from Gough Island (Le Maitre 1962).

Sodium and potassium. Both sodium and potassium increase throughout, the potassium at a slightly greater rate, so that towards the end of the series it becomes more abundant than sodium. The potassium content is high for a mid-oceanic assemblage. The only other volcanic areas in which potassium is equally abundant appear to be the Marquesas in the central Pacific and the Kerguelen Islands in the Southern Ocean.

Rubidium. The high rubidium content found in the specimens from Tristan is also characteristic of those Marquesan rocks analyzed by Nockolds & Allan (1954). In the Tristan examples, rubidium increases steadily towards the felsic end. However, the Rb/K ratio shows little change and in fact appears to fall slightly for the most trachytic members. If potassium is removed at all during crystallization rubidium must be removed with equal or slightly greater facility.

Niobium. Niobium increases from the earlier members of the series to a relatively constant value of about 150 p.p.m. Presumably, during the intermediate stages, it is able to enter crystal lattices, perhaps replacing titanium, thus preventing any further increase of niobium in the liquid.

The niobium content is markedly higher than in most other basic rocks. Unfortunately, there seem to be no data for other suites of basic oceanic volcanic rocks, but analyzed Karroo basalts contained less than 30 p.p.m. (J. M. Rooke, personal communication).

Zirconium. The zirconium content of the series rises from 300 p.p.m. in the basalts and 350 to 400 p.p.m. in the intermediate rocks to about 500 p.p.m. in the final trachytes. This concentration is of the same sort of order as in the Polynesian and Hawaiian series of Nockolds & Allan (1954) and in Gough Island (Le Maitre 1962).

Lithium. Lithium has a regular increase from about 4 to 6 p.p.m. in basalts to 15 to 20 p.p.m. in the final liquid, and resembles potassium and rubidium in its relative change in concentration.

5·2. *Petrogenetic observations*

Two interesting problems associated with the petrology of the Tristan da Cunha Group are the presence of leucite and the significance of the plutonic xenoliths. These problems are still being investigated and more detailed work is in progress. In view of this, the following discussion is confined to generalizations.

5·2·1. *The significance of leucite*

Before this present investigation leucite had not been recorded from Tristan. A short note has already appeared in print (Le Maitre & Gass 1963). Schwarz (1905) described some rocks from Tristan which undoubtedly contained leucite, e.g. 'a grey rock with lighter rounded spots' but misidentified it as 'clear residual glass showing a certain amount of bi-refringence' (p. 47). He also described several other rocks with light-coloured spots in hand specimen, a feature characteristic of the leucite-bearing rocks, but in all cases took the leucite for glass.

The occurrence of leucite on Tristan exhibits several most unusual features. First, leucite normally occurs as early formed, euhedral phenocrysts or euhedral groundmass material; on Tristan it occurs interstitially as a late stage product, except in the new lava where it occurs as subhedral crystals in the groundmass. A similar interstitial habit has also been noted in some basanites from the Causses of the Massif Central in France (Jérémine, Gèze & Christophe-Michel-Lévy 1958) but this, to the authors' knowledge, is the only other recorded occurrence of interstitial leucite. Secondly, with few exceptions, leucite-bearing lavas are confined to continental environments. As far as is known the only recorded instances of leucite rocks occurring on oceanic islands are those of the Cape Verde Islands (Part 1950), Kerguelen (Edwards 1938) and the Marquesas (Lacroix 1931). However, the Cape Verde Islands are structurally related to the African continent and not part of the ocean basin proper, while on Kerguelen the geological evidence suggests that the island may be related to the Antarctic continent. Although the Marquesas are indisputably oceanic in character the rock described by Lacroix as a 'phonolite leucitique' does not appear from his description to contain any leucite, but only pseudomorphs after a cubic mineral which he deduces was originally leucite.

Chemically, the leucite-bearing lavas from Tristan are rather interesting in that they do not differ markedly from other oceanic rock suites. In most continental leucite-bearing rocks K_2O is often very much greater than Na_2O, whilst in those from Tristan K_2O is always less than Na_2O. Admittedly, for a given SiO_2 content the value of K_2O is greater than in many oceanic rock suites, but so, to a lesser extent, is Na_2O; the effect of this can be seen in figure 18. It should be noted that leucite is never present in the CIPW norm, although large amounts of nepheline are present. This reflects an inherent weakness in the CIPW norm calculation and for these particular rocks it would be more realistic to desilicate the *or* before *ab* giving an assemblage that would be closer to the mode, i.e. *or*+*ab*+*leu* instead of *or*+*ab*+*ne*. The virtual absence of nepheline in itself is of interest as in most undersaturated oceanic lavas the first undersaturated mineral to appear in the mode is either nepheline or analcime.

Two factors which may possibly have some bearing on the development of the leucite are: the desilicating effect of the resorption of the undersaturated basaltic amphibole; and the high volatile content of the lavas, for which there is abundant field evidence, which may have helped to suppress the field of leucite in the early stages of crystallization. At this stage, however, this can be no more than speculation and the solution to this problem must await more detailed knowledge of the phase relations of the minerals involved and in particular the composition of the feldspars associated with the leucite.

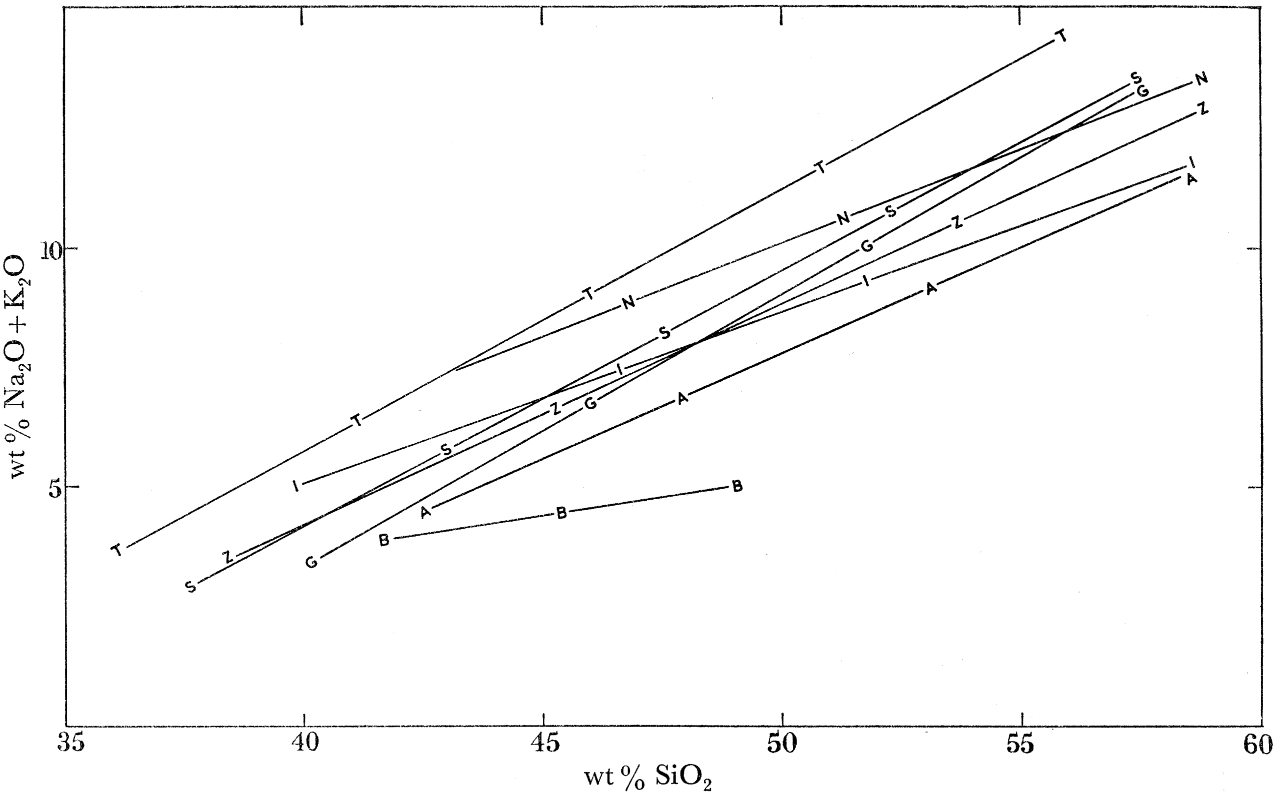

FIGURE 18. Comparative chemistry: $K_2O + Na_2O/SiO_2$ for Mid-Atlantic Ridge Islands.
T, Tristan; N, Nightingale; I, Inaccessible; Z, Azores;
A, Ascension; S, St Helena; G, Gough; B, Bouvet.
(See § 6·4, p. 538)

5·2·2. *The plutonic xenoliths*

A brief petrographic description of these xenoliths is given in § 2·6. There are three likely sources for these nodules: they may be accidental; they may be remnants of the source rock from which the containing magma was derived by partial melting; or they could have crystallized under plutonic conditions from the same magma as the extrusive rocks in which they occur. The last explanation seems the most feasible.

From the petrography it would appear that the stable mineral assemblage in the xenoliths at depth, prior to eruption was essentially amphibole, pyroxene, plagioclase and ore. As deduced in § 2·6, the plutonic xenoliths from lavas show the conversion of amphibole to pyroxene, whilst in xenoliths from pyroclastic centres, the pyroxene is sometimes altering to amphibole. The apparent reversal of reaction between the two volcanic environments might be explained in the light of the work of Yoder & Tilley (1962) and Kennedy (1955).

Pyroxene and amphibole might co-exist at depth if there was insufficient water to provide all the hydroxyl as well as to maintain the pressure conditions for amphibole stability. Conversion of pyroxene to amphibole in a magma ascending slowly towards the surface under conditions of constant water pressure could be favoured by any of three factors. (i) In a magma column at equal water pressure at all levels the water content would be highest at the top. Hence, if equilibrium or equipotential conditions are maintained the water content will increase in a rising column and decreases in a magma reservoir below (Kennedy 1955). An increasing water content would permit further conversion of pyroxene to amphibole. (ii) Under constant water pressure, but diminishing total pressure the magma could move from the field of pyroxene stability to one of amphibole stability. (iii) Fall in temperature due to heat loss by conduction, could move the magma into the amphibole stability field. Thus, in a hydrous magma which might be expected to lead to explosive eruption, amphibole would form at the expense of pyroxene. Final eruption as scoria would quench the liquid and preserve the amphibole phase.

In a less hydrous magma of effusive eruptive tendencies amphibole would be less likely to form than pyroxene. On the eruption of the fluid lava under surface conditions of negligible water pressure, it is possible that the amphiboles in the xenoliths are partly converted to pyroxene which is a stable phase under these conditions.

5·3. *Differentiation*

Within individual members of the volcanic successions of the Tristan da Cunha Group, field or microscopic evidence for the evolutionary history and crystal fractionation of the magma is not to be expected. Such evidence as was found was of a minor nature. The only major information about the differentiation processes is found by the comparison of lavas from different episodes as depicted in the variation diagrams (figures 13 to 17).

The chemical variation of the major oxides can be seen in a simplified form in table 8. This table lists the composition of four average rock types together with their norms. The averages are taken only from Tristan rocks. SiO_2, Al_2O_3, Na_2O and K_2O all increase steadily throughout the series while the other five oxides decrease. This variation is reflected in the normative minerals. There is a steady increase in *or*, *ab* and *ab* + *ne* from the basic to acid end of the series, while *an* decreases overall. Both *di* and *ol* decrease rapidly, *ol* being absent in the last two norms. It is also interesting to note that *di* predominates markedly over *ol*. *Il* and *mt* also decrease steadily throughout. These changes are similar to those found in many other suites of volcanic rocks.

The final rocks, the trachytes, do not fall on the nepheline eutectic of the system quartz–nepheline–kalsilite but lie half-way between the nepheline eutectic and the albite–orthoclase join, slightly inside the leucite field. The mineralogy of the plutonic xenoliths indicates that basaltic hornblende is a stable phase at depth under hydrous conditions. Both the basaltic hornblende of the xenoliths and the plutonic xenoliths themselves are distinctly lower in silica than any of the basalts. If one makes the assumption that the xenoliths are derived as a direct result of crystallization in the differentiating magma, then crystallization and separation at depth of this material with low silica content would prevent any further undersaturation in silica in the residual liquid and could explain why the final members are trachytic and not phonolitic. Had the magma been less hydrous, so that amphibole was not a normal plutonic mineral, one would have expected the end members to be considerably more undersaturated. Equally, if the xenoliths were derived from pre-existing material it could be argued that their assimilation into a 'normal' magma could lead to an undersaturated Tristan type; the difference in undersaturation between the early and late stage rocks being a measure of the temperature dependence of assimilation.

TABLE 8. COMPOSITION OF AVERAGE ROCK TYPES

wt. %	1	2	3	4
SiO_2	43·1	46·7	54·9	60·0
TiO_2	4·1	3·6	1·8	0·9
Al_2O_3	13·1	17·3	19·6	20·2
Fe_2O_3	5·5	3·8	2·8	2·1
FeO	8·5	7·1	2·9	1·1
MgO	9·0	4·7	1·5	0·5
CaO	12·4	9·7	5·7	2·3
Na_2O	2·7	4·1	5·9	6·8
K_2O	1·6	3·0	4·9	6·1
norm				
or	9·5	17·7	29·0	36·0
ab	4·6	11·2	29·8	41·1
ne	9·9	12·7	10·9	8·9
an	18·9	20·0	12·5	6·6
di	33·8	22·6	8·1	2·7
ol	7·6	3·5	—	—
wo	—	—	2·2	0·6
il	7·8	6·8	3·4	1·7
mt	8·0	5·5	4·1	0·9
hm	—	—	—	1·4
$\frac{FeO \times 100}{FeO + MgO}$ in femics	12·7	20·4	0·7	0
diff. index	24·0	41·6	59·7	76·0

1, Average alkali basalt (3 anals.); 2, average trachybasalt (10 anals.); 3, average trachyandesite (9 anals); 4, average trachyte (4 anals.).

There is repetition at different times in the eruptive history of trachytes and of trachyandesites. Trachytes occur as weathered and eroded remnants beneath the sequence of basalts in the Main Cliffs, as well as in young features at the summit of the Peak. If the trachytes are the final product of differentiation, this has been a repeated process with new parental material introduced at intervals. At the same time, the unusual features of those basalts which perhaps represent the parental material are also repeated. For example, analysis 347 is of a basalt from near the bottom of the Main Cliff sequence at Pigbite, east of the Settlement, while analyses 20, 21 and 622 are all from the lava making up the Settlement coastal strip, a relatively late feature (table 9).

As can be seen, the similarity is almost as close for the trace elements as it is for the major elements. Equally, trachytes and trachyandesites occurring at different times in the volcanic sequence are closely similar to the other trachytes and trachyandesites, both in major and in trace elements.

This repetition of closely similar basaltic material at different stages in the volcanic sequence does indicate that new material introduced into the magmatic cycle has been of a similar nature on each occasion.

In general, it is not possible to study differentiation within a single eruptive episode. However, systematic changes do occur. For example analyses 21 and 622 are of the very extensive lavas from the Hillpiece centre, while analysis 20 is from the final stage in the Hillpiece episode, a perfectly preserved scoria cone (table 10).

TABLE 9

	no. 347	average of nos. 20, 21, 622
SiO_2 (%)	46·4	46·2
MgO (%)	4·6	4·7
Na_2O (%)	4·0	4·0
K_2O (%)	3·1	3·1
Rb (p.p.m.)	160	170
Sr (p.p.m.)	1400	930
Ba (p.p.m.)	1000	880
Nb (p.p.m.)	110	127

TABLE 10

	no. 21	no. 622	no. 20
SiO_2 (%)	46·00	46·07	46·48
Al_2O_3 (%)	17·03	17·06	16·68
total Fe as FeO (%)	10·88	10·65	11·01
MgO (%)	4·80	4·72	4·65
CaO (%)	9·54	9·35	9·40
Na_2O (%)	4·04	4·01	3·80
K_2O (%)	3·11	3·16	3·07
Sr (p.p.m.)	1100	900	800
Ba (p.p.m.)	1000	850	800
Ni (p.p.m.)	10	10	< 10

TABLE 11

	nos. 518	617	nos. 627	657
SiO_2 (%)	54·5	54·8	54·7	54·9
Al_2O_3 (%)	19·3	19·1	19·9	19·6
total Fe as FeO (%)	5·6	5·8	5·5	4·8
MgO (%)	1·5	1·5	1·1	1·4
CaO (%)	5·8	5·6	5·6	5·7
Na_2O (%)	6·0	6·0	6·0	6·0
K_2O (%)	4·9	4·9	5·1	5·1
Rb (p.p.m.)	220	210	260	230

Certain changes are those to be expected, an increase in silica and a decrease in magnesium relative to iron with time. However, the diminution in sodium, potassium, strontium and barium is not expected.

Changes also occur among the lavas from the 1961 eruption. Analyses 518 and 617 are of material from the original dome and its collapsed wall. Analyses 627 and 657 are of later lava from the north-eastern edge of the lava field and from a bomb thrown from the volcano (table 11).

In this example, both iron and magnesium have decreased, magnesium to a greater degree, so that the ratio Mg/Fe has also decreased. Though calcium and sodium remained unchanged, potassium and rubidium have increased. These changes from the first eruptive phase to material from the middle to late stages of the eruption must have been due either to compositional differences in different parts of the magma prior to eruption, or else have been superimposed on the magma during the period of eruption. If they are due to differentiation within the magma during the eruption, then they occurred in a period of about 2 months.

Even more pronounced changes are seen in a comparison of material from the 1961 eruption and from Stony Hill, a centre active about 300 years ago (table 12). Though these centres are at opposite ends of the island; their compositions and eruptive features are very similar, so that they would appear to have been derived from a common body of magma.

TABLE 12

	Stony Hill, average of nos. 230, 232	1961 Centre, average of nos. 518, 617, 627, 657
SiO_2 (%)	54·0	54·7
Al_2O_3 (%)	19·3	19·5
MgO (%)	1·7	1·4
total Fe as FeO (%)	5·9	5·4
CaO (%)	6·2	5·7
Na_2O (%)	5·1	6·0
K_2O (%)	4·5	5·0
Rb (p.p.m.)	200	230
Sr (p.p.m.)	1250	1400
Ba (p.p.m.)	1100	1300

Here the changes are entirely those expected; a reduction in iron and magnesium, a decrease in the Mg/Fe ratio and an increase in sodium and potassium and also in barium, strontium and rubidium. The relatively short time interval of about 300 years between the two episodes indicates that crystal fractionation could be very effective over periods as short as a few thousand years in volcanoes of this type.

A final point of petrological interest is in the differences between the three islands. The Tristan rocks are more undersaturated (higher normative nepheline) than those from the other islands. A plot of normative nepheline against differentiation index gives a wide scatter of points, due partly perhaps to the effect of oxidation on normative constituents. However, the average content of normative nepheline is instructive.

TABLE 13

	% normative nepheline		
	Tristan	Nightingale	Inaccessible
trachybasalt	10·0	6·6	5·7
trachyandesite	10·4	2·1	0
trachyte	6·7	3·4	0

The rocks from Tristan differ distinctly in degree of saturation from those of Inaccessible and Nightingale, although in other respects and especially in their abnormal content of some trace elements there is a close similarity between the islands. Tristan is considerably younger than Nightingale and Inaccessible so that the difference in composition between islands can be ascribed to a time effect rather than a geographical one.

Whether the differences are in the original parent magmas or in the effect of the differentiation processes on these is uncertain. However, some of the Inaccessible and

Nightingale basalts are just as undersaturated as the Tristan basalts. This and the identical trace element compositions of the different islands indicate that it is likely that the parental material has been equally undersaturated and closely similar for each island, but that the differentiation processes that formed the Nightingale and Inaccessible rocks differed from the later differentiation processes of Tristan in producing more saturated derivatives.

5·4. *Magma genesis*

The volcanic assemblage from the Tristan da Cunha Group differs from most other oceanic basaltic associations in the relatively high content of potassium, rubidium, strontium, barium and niobium, and in the low content of nickel and chromium. The only closely comparable association for which data are available is that of the Marquesas (Nockolds & Allan 1954).

In Tristan, the repetition of basic and feldspathic material indicates that the most abundant local basalt type is likely to be parental, in the sense that intermediate and trachytic members are derived from it. There is no sign of a tholeiitic parental magma even though new magma has been injected into the system from time to time.

It is considered that on Tristan the parental magma from which the other members are derived is the characteristic high-potassium type. However, it is not suggested that this is primary, in the sense of being first-formed or directly-formed by melting in the mantle. The Tristan basalts are abnormal not only in their major element content but also in their trace element content. The low nickel and chromium and high potassium, rubidium, barium and niobium indicate that this parental material is itself the product of some enrichment or differentiation processes.

The absence of known sialic crust does not permit assimilation of crustal rocks as a source of the potassium and trace elements. It is likely that the magma is the result of mantle processes with no influence of crustal material. Four possibilities arise:

(*a*) the magma is derived by melting in a region in the mantle of abnormal composition and not normally tapped by volcanism;

(*b*) that normal basaltic magma, formed at depth, has differentiated within the mantle to give a liquid with some features of residual liquids, high potassium, rubidium, barium, niobium, volatiles, etc. Those features of basic rocks, low silica content and high Mg/Fe ratio are preserved by reaction with mantle material;

(*c*) that magma formed at depth has become enriched in the elements characteristic of residual liquids by a process akin to zone refining;

(*d*) that a very small degree of partial fusion has resulted in a relatively high concentration of trace elements through their selective melting.

The possibilities (*b*), (*c*) and (*d*) have been discussed in more detail by Harris (1957).

No matter how the parental magma has acquired its unusual characteristics, it is considered to have been tapped off at intervals and admitted to the region of normal differentiation, in which trachyandesites and trachytes have formed.

The rocks of the Tristan area are attributed to a two-stage process, a first in which the basalt has acquired the high concentration of residual elements characteristic of Tristan and a second, normal differentiation process resulting in the formation of trachyandesites and trachytes.

6. Comparison with other Mid-Atlantic Ridge islands

This comparison is confined to five of the islands on the Mid-Atlantic Ridge: Bouvet, Gough, St Helena, Ascension and the Azores. St Paul Rocks are not included as they consist of highly mylonitized dunite (Tilley 1947) and occupy a unique position in the petrology of the Atlantic.

For convenience, the comparison is divided into four sections: physiography, volcanology, petrography and chemistry. The data for each section are presented in tabular form and only selected features are commented upon in the text. The main geological references used in the compilation of these tables are: Bouvet (Broch 1946); Gough (Le Maitre 1960, 1962); St Helena (Daly 1927); Ascension (Daly 1925); Azores (Esenwein 1929; Friedlaender 1929).

6·1. *Comparative physiography* (table 14)

Unlike Bouvet, Gough and Ascension, which are single volcanic peaks, St Helena has an associated peak (500 ft. below sea-level some 60 miles to the west); the Tristan da Cunha Group has three major peaks whilst in the Azores both single and double peaks occur.

Table 14. Comparative physiography

	Bouvet	Gough	Tristan	St Helena	Ascension	Azores
number of islands in group	1	1	3	1 (+1)	1	10
approx area in square miles	27	25	40 Tr, $1\frac{1}{2}$ Ni, 4 In	45	38	160 Pi, MM 300–5
height above sea-level (ft.)	3068	2986	6760 Tr, 1105 Ni, 1840 In	2697	2817	7613 Pi, Av. 3000–3500
height above sea-floor (ft.)	16000	13000	20000	17000	9000	16000
distance in miles from supposed Mid-Atlantic Rift	0	350 E.	300 E	480 E	70 W	80 W–250 E
distance in miles from axis of Mid-Atlantic Ridge	0	210 E	230 E	500 E	90 W	30 W–300 E

Tr, Tristan; Ni, Nightingale; In, Inaccessible; Pi, Pico. MM, maximum and minimum values, Av., average values; E, east; W, west.

There is a marked similarity in the height of many of the islands, Bouvet, Gough, St Helena, Ascension and several of the Azores being approximately 3000 ft. above sea-level. It is also interesting to note that Tristan and Pico in the Azores, which are both near perfect cones, have a maximum height above sea-level of the order of 7000 ft.

The distances in land miles from the various islands to the axis of the Mid-Atlantic Ridge and to the supposed Mid-Atlantic Rift have been compiled from the physiographic charts of Heezen & Tharp (1957, 1961); profiles taken by the *Meteor* (Stocks & Wüst 1935); profiles published by the Woods Hole Oceanographic Institute as part of their contribution to the I.G.Y.; and from information supplied by Rear-Admiral E. G. Irving, Hydrographer of the Navy. The errors involved, owing mainly to the uncertainty in the location of the ridge, are probably of the order of ± 20 miles. The majority of the islands lie well to the east of the centre of the ridge, only Ascension and the two most westerly islands in the Azores, Corvo and Flores, lying to the west.

6·2. *Comparative volcanology* (table 15)

There has been no historical record of any eruptions on Bouvet, Gough, St Helena or Ascension, although one of us (P.E.B.) who landed on Bouvet in April 1964 established that there had been volcanic activity on that island during the period 1955–58 and from the evidence of an ash band in a peat boring from Gough, this island erupted as little ago as 2345 ± 120 years B.P. (Hafsten 1960). Many of the volcanic features on Ascension also look remarkably young (Daly 1925). The Azores have a long recorded history of eruptions adequately summarized by Friedlaender (1929), the most recent eruption being that of Capelhinos on the island of Fayal in 1957–58 (Castello Branco *et al.* 1959).

Table 15. Comparative volcanology

	Bouvet	Gough	Tristan*	St Helena	Ascension	Azores
recorded historical volcanic activity	recent†	none	recent	none	none	recent
eruptive sequence	?	(T) B, T, B, T, B,	no apparent rhythmic sequence	B, T	B, T, B	B, T
volcanic form	?	complex mass	single cone with parasitic centres	complex mass possibly a doublet: fissure eruptions?	irregular shallow cone with parasitic centres	single and complex cones with parasitic centres
erosional state	ice capped	deeply dissected	very little erosion except for sea-cliffs	deeply dissected	very little erosion	variable
dyke characteristics	recorded in pyroclastic centres	radial dyke pattern: swarms in lower horizons	marked radial dyke pattern	multiple linear dyke swarms; especially in pyroclastic complexes	very few	few

* Not including Nightingale and Inaccessible.
† Personal communication (P. E. Baker).

B, Basaltic phases.
T, Trachytic phases.

A characteristic feature of all the islands for which there are available data is that trachytic eruptions have interrupted, at intervals, the sequence of basaltic eruptions. Dykes are rather variable in their characteristics, some islands having abundant dykes with a well-defined radial pattern (Gough and Tristan) while others have very few (Ascension and Azores). The majority of the islands have parasitic cinder cones.

6·3. *Comparative petrography* (table 16)

In addition to the literature, data for this table has been collected from a study of innumerable thin sections in the rock collections of the British Museum (Natural History).

Very few rocks have been described from Bouvet and the apparent lack of intermediate types is probably due to this. However, rhyolites and rhyolitic obsidians are present, a feature which seems to be confined to Bouvet and Ascension. Accumulative volcanic rocks have not been recorded from either of these islands.

All rock types, from basalt to trachyte, are well represented on all islands except Bouvet. From a trachytic composition the late differentiates trend either towards phonolites or rhyolites; the Azores are interesting in possessing both phonolitic and rhyolitic tendencies.

TABLE 16. COMPARATIVE PETROGRAPHY

	Bouvet	Gough	Tristan	St Helena	Ascension	Azores
VOLCANIC ROCKS						
ankaramites, etc.	—	X	X	X	—	X
alkali basalts	X O	X	X O	X	X	X
trachybasalts	—	X O	X	X O	X O	X O
trachyandesites	—	X	X A	(x)	X	X
trachytes	—	X	X	X	X	X
phonolites	—	(x)	X	X A	— A	(x) A
rhyolites	X A	—	—	—	X	(x)
obsidians	X	—	—	—	X	—
approx. % of basaltic rocks	?	45	95 Tr, 5 Ni, 90 In	98	88	High
XENOLITHS						
peridotitic	—	(x)	—	—	X	X
gabbroic	—	X	X	—	X	X
dioritic	—	—	—	—	X	—
syenitic	—	—	—	—	X	—
granitic	—	—	—	—	X	—
CHARACTERISTIC MINERALS OF GABBROIC TYPES						
olivine	—	X	(x)	—	X	X
hypersthene	—	X	—	—	X	—
amphibole	—	—	X	—	X	—

X, Signifies occurrence of a rock type or mineral. (x), signifies rare occurrence of a rock type or mineral. O, Crystallization range of olivine. A, Crystallization range of amphibole. Tr, Tristan; Ni, Nightingale; In, Inaccessible.

The crystallization ranges of olivine and amphibole are interesting as they appear to show a certain amount of incompatibility between the two minerals, the maximum amount of overlap apparently being in the Azores. The olivines gradually become more iron-rich in the later differentiates and the amphiboles range from basaltic hornblende in the intermediate types to alkali amphibole in the later differentiates. Unlike the olivines, however, there does not appear to be a continuous gradation in the composition of the amphiboles.

On the majority of the islands, for which information is available, basaltic rocks predominate decisively over trachytic. Two exceptions to this are Gough and Nightingale.

Xenolith material has been recorded from all the islands except Bouvet and St Helena. The commonest are the gabbroic and peridotitic types; the dioritic, syenitic and granitic types being confined to Ascension. Although no peridotitic types have been recorded from Tristan, gabbroic types are abundant and the majority contain basaltic hornblende as an essential constituent, only rarely olivine; hypersthene is characteristically absent. The gabbroic types from Gough and Ascension are both characterised by the presence of hypersthene. Although hypersthene does not crystallize from an alkali magma under normal conditions, it is possible to crystallize it at depth under pressure (Yoder & Tilley 1962, p. 510). The origin of these xenoliths is briefly discussed in § 5·2·2.

6·4. *Comparative chemistry* (table 17)

The analyses of the average Tristan basalt and trachybasalt are from table 8. The remaining 'basalt' averages are taken from Le Maitre (1962, p. 1335).

For a given SiO_2 content the Tristan rocks are characterized by high Na_2O+K_2O; this can be seen in figure 18, p. 529, in which SiO_2 is plotted against Na_2O+K_2O for the various islands.

TABLE 17. COMPARATIVE CHEMISTRY

	Bouvet, 'basalt'	Gough 'basalt'	Tristan basalt	Tristan trachybasalt	St Helena 'basalt'	Ascension, 'basalt'	Azores, 'basalt'
SiO_2	50·3	47·7	43·1	46·7	47·9	50·1	45·7
TiO_2	2·6	3·2	4·1	3·6	3·6	2·8	2·3
Al_2O_3	18·1	15·2	13·1	17·3	16·4	16·3	14·1
Fe_2O_3	4·4	2·3	5·5	3·8	3·9	4·1	4·8
FeO	5·8	8·7	8·5	7·1	8·2	7·5	7·4
MgO	4·3	9·7	9·0	4·7	6·4	5·4	10·3
CaO	10·4	8·9	12·4	9·7	8·7	8·8	12·4
Na_2O	3·2	2·7	2·7	4·1	3·8	3·7	2·4
K_2O	0·9	1·6	1·6	3·0	1·1	1·3	0·6
Q (F)	2·46	—	—	—	—	—	—
or (F)	5·32	9·46	9·46	17·73	6·50	7·68	3·55
ab (F)	27·07	22·13	4·55	11·17	29·65	31·31	15·31
ne (F)	—	0·39	9·91	12·74	1·36	—	2·71
an (F)	32·37	24·63	18·90	19·95	24·45	24·03	25·93
di (P)	15·32	15·67	33·79	22·59	15·03	15·82	28·30
hy (P)	6·14	—	—	—	—	5·50	—
ol (P)	—	18·30	7·63	3·48	10·52	4·39	12·88
il (O)	4·94	6·08	7·79	6·84	6·84	5·32	4·37
mt (O)	6·38	3·34	7·97	5·51	5·65	5·95	6·96
total *F*	67	57	43	62	62	63	48
total *P*	22	34	41	26	26	26	41
total *O*	11	9	16	12	12	11	11
Mol % Fe in *P*	16	22	13	20	22	25	15
or	8	16	18	24	10	12	7
ab (+*ne*)	43	42	46	49	52	51	42
an	49	42	36	27	38	37	51
diff. index (*Q*+*or*+*ab*+*ne*)	35	32	24	42	38	39	22

However, the chemical differences between the various islands are probably best seen in the CIPW norms. The high alkalies for a given SiO_2 content in the two Tristan averages are reflected in the large amounts of *ne* (nepheline) in the norms. These two analyses lie well inside the field of alkali basalts defined by Yoder & Tilley (1962). Gough, St Helena and the Azores also have small quantities of *ne* in their norms and lie close to the critical plane of silica undersaturation. Ascension, on the other hand, has *hy* (hypersthene) in the norm and would lie in the field of olivine tholeiites while Bouvet, which contains normative *Q* (quartz), would lie in the tholeiite field; in all other respects, however, these two basalts are alkaline in character and exhibit none of the mineralogical features commonly associated with true tholeiitic basalts. Both these islands have rhyolitic (i.e. quartz rich) late differentiates, a fact which may have been governed by the slightly more silica-saturated starting composition.

Other useful comparisons can be gained by simplifying the norm into certain summations and compositional ratios, hence the values total F, total P and total O (FPO) which represent the ratios of feldspathic, ferromagnesian and ore minerals; the molecular per cent of iron in the ferromagnesian minerals (% Fe); the molecular composition of the feldspars (*or ab an*) and the differentiation index (DI). If the Tristan trachybasalt is compared with St Helena and Ascension basalts there is a marked similarity between the three FPO ratios, the % Fe and the DI, the values being approximately 62/26/12, 22 and 40 respectively. Here, however, the similarity ends as the *or ab an* ratios for the Tristan trachybasalt (24/49/27) are very different from the values for St Helena and Ascension (approximately 11/51/38). This again reflects the high K_2O values for Tristan. Similarly, the Tristan basalt compares favourably with the Azores in FPO, % Fe and DI values but again *or ab an* are markedly different, 18/46/36 and 7/42/51 respectively.

Conversely, if averages with similar *or ab an* ratios are compared, e.g. the Gough and Tristan basalts, then the FPO, % Fe and DI values differ markedly.

6·5. *Conclusions*

Compared with other islands on the Mid-Atlantic Ridge Tristan is higher in alkalis and relatively undersaturated with respect to silica. This is made apparent by the presence of leucite in the lavas, by the presence of large amounts of nepheline in the norms and by the high value of *or* in the *or ab an* ratios.

There also appears to be some sort of compositional variation with respect to the location of the islands and the ridge. Both Bouvet and Ascension have strongly rhyolitic late differentiates and lie close to the centre of the ridge. Moving away from the centre of the ridge the next islands encountered are Gough and Tristan, both of which have trachytic late differentiates with slight phonolitic tendencies. Further out still is St Helena with definite phonolitic late differentiates. The Azores which straddle the centre of the ridge have both rhyolitic and phonolitic tendencies in their late differentiates. The trend, therefore, would appear to be one of increased silica undersaturation with increase in distance from the centre of the ridge and it is interesting to note that if this is carried beyond the Mid-Atlantic Ridge, it still holds true, e.g. Canary and Cape Verde Islands, Fernando de Noronha and the Trinidad–Martin Vas Group are all strongly phonolitic and alkaline in character.

PART III. THE 1961 ERUPTIVE CENTRE

1. Introduction

Within historic times, volcanic activity in the vicinity of the Mid-Atlantic Ridge has been restricted to Iceland, the Azores and Bouvet, the most recent eruptions being those of Askja (1961) and Capelhinos (1957–58) respectively, whilst the existence of a recent flow on Bouvet has been mentioned (P. E. Baker, personal communication).*

* In March 1964, P. E. Baker landed on the west coast of Bouvet and established that there had been volcanic activity during the period 1955–1958. (A note entitled 'A recent volcanic eruption on Bouvet, South Atlantic,' is being submitted to *Nature*.)

St Helena shows no sign of recent activity (Daly 1927) but Ascension has relatively fresh-looking lava flows, though these predate settlement (Daly 1925). There is no evidence of very recent activity on Gough Island, and Marion and Prince Edward Islands have not been investigated. Previous accounts of Tristan geology (Douglas 1930; Campbell Smith 1930; Dunne 1941) make no suggestion that any of the centres had recently been active, but it now appears that the Stony Hill parasitic centre in the south of the island is of the order of 200 to 300 years old (pp. 482 to 486) and was, most probably, the youngest centre before the 1961 eruption.

Volcanic activity was resumed on Tristan in October 1961, with the formation of a new secondary centre and lava field on the Settlement Plain; it was not accompanied by sympathetic activity at either the summit crater or at any of the pre-existing secondary cones. The proximity of the new eruptive centre, and the precursory earth tremors and rock falls in the vicinity of the Settlement led to the evacuation of the entire population. The wide coverage given to these events in the press tended to exaggerate the magnitude of the eruption, which was in fact of a relatively minor character. The area occupied by the new lava is just over 0·2 sq. mile compared with the island's total area of approximately 40 sq. miles.

2. Prelude to the eruption

No earthquakes had ever been experienced on Tristan prior to August 1961. During the week beginning 6 August, about 2 months before the beginning of the eruption, slight shocks were felt in the vicinity of the Settlement and also at Sandy Point on the east coast. Tremors increased slightly in intensity and frequency over the following 3 weeks, but at the end of August there was a lull during which there were no perceptible earthquakes.

Early in September the tremors recommenced with greater frequency and violence. The Administrator, Mr P. Wheeler, reports that there were also 'many minor rumbles and subterranean thumpings at this time'. A constant alert was maintained at the Settlement, the precise time of each tremor being recorded: in addition each shock was graded A, B, C or D according to its intensity. It would appear that these grades correspond roughly to the following ratings on the Modified Mercalli Scale (Richter 1958): A = 3, B = 4, C = 5, and D = 6. The tremors are stated to have been less perceptible in the open than in the houses, many of which developed slight cracks.

Parties were sent to other localities on Tristan to try to determine the area over which the earthquakes could be felt. A group camping on Hillpiece about 1 mile to the south-west of the Settlement experienced tremors, at least one of which is believed to have been of greater intensity than at the Settlement. This particular earthquake is stated to have had a directional movement from east to west. Tremors were also felt on the edge of the Base above the village and at each end of the Settlement Plain. At Stony Beach on the south coast of the island 7 miles from the Settlement no tremors were experienced, nor were any felt by a party on Nightingale Island at the end of September. The seismic activity reached a climax during the first 5 days of October, and although the shocks were now infrequent, only about six being recorded in this period, they were all sufficiently severe to warrant a 'D' grading. Although ornaments were dislodged from shelves and pictures shaken from the walls, none of the houses suffered any serious structural damage.

From the data assembled by the residents during this period it is possible to make a rough estimate of the depth of focus of the earthquakes. Assuming an epicentre close to the Settlement and ascribing an intensity of 6 to the strongest shocks at that locality, an intensity of 4 at a distance of 3 miles and 1 at a distance of 7 miles it would appear that the hypocentre was at a depth of approximately 1 mile. The magnitude was three and the energy released was of the order of 10^{16} ergs.

Concurrently with these 'D' grade tremors a series of about sixty rock falls occurred, particularly from near the top of the 2000 ft. cliffs behind the Settlement; they involved the removal of soil and loose talus and sometimes considerable volumes of the underlying rock were dislodged. An old volcanic neck immediately behind the Settlement was the site of the greatest land slips. The falls from this neck numbered as many as twenty per day, continued on this scale for 4 days and damaged the water supply installations immediately below. Rock falls also occurred from the 60 ft. coastal cliffs behind the Factory to the north-east of the village.

The water supply to the village was cut off on 8 October when earth movements buckled and disrupted the pipes. Calculations based on a maximum elevation of one water pipe by 16 in. over a distance of 12 ft. indicate a maximum temporary extension at the surface of the earth of the order of 1 in 50, at a distance of 550 yards from the point of development of the volcanic centre. The same phase of earth movements resulted in the development of a number of small surface cracks in the eastern part of the Settlement; these fissures generally had a north–south trend and when they passed through houses it was often difficult to open and close doors and windows. The following day, however, the cracks sealed and doors and windows could be opened and closed as usual. The same afternoon a large crack opened near Diamond Beacon (Admiralty Chart 1759); it was roughly parallel to the Main Cliffs and about 300 yards from the eastern end of the Settlement. On the south side of this crack, the ground began to swell and within two hours a pronounced mound 30 ft. in diameter and 20 ft. high had developed. The mound was still partly covered by grass, and its top and flanks were lacerated by fractures, but neither smoke nor heat was observed and there were no accompanying earth tremors.

The nature of the Tristan tremors resembles seismic disturbances which in other instances have preceded a volcanic eruption, e.g. Capelhinos 1957 (Castello Branco *et al.* 1959). In other instances, such as the seismic crisis at Montserrat 1933–35 (Perret 1939), comparable earthquakes have not terminated in an eruption though a volcanic origin is probably to be ascribed to this type of seismic activity, whether or not an eruption occurs. The absence of any well-defined correlation between the seismic pattern and the incidence of eruption frustrates any attempts at prediction. The characteristics of a volcanic earthquake were well illustrated on Tristan. The hypocentre or depth of focus of such an earthquake is usually very shallow and therefore there is a very rapid decrease in intensity of the tremors with increasing distance from the epicentre; it will be recalled that severe shocks at the Settlement were not perceptible at Stony Beach only 7 miles away. The fact that tremors felt at the Settlement increased in intensity from the beginning of August to October can probably be attributed to the approach of the focus of disturbance as the magma ascended towards the surface. Mr Wheeler was inclined to the opinion that the earlier earthquakes were less localized than the later ones; this too might be related to the continued advance of the hypocentre towards the surface. The cessation of earth tremors as soon as the eruption commenced suggests that the extrusion of the magma at the surface relieved stresses which previously had been accommodated by earth movements.

3. The eruption

A red glow issuing from the newly formed mound was the first definite indication of a volcanic eruption. This observation was made at 2 a.m. G.M.T. on the morning of 10 October from the M.V. *Tristania* lying off the Settlement. By daybreak the mound had developed into a dome or tholoid some 60 ft. high and 150 ft. in diameter. It continued to grow throughout the day, lateral expansion being chiefly due to the accumulation of blocks, which broke loose from near the summit and rolled to the foot of the slopes. Swellings are reported to have formed intermittently on the flanks of the tholoid which burst and scattered rock fragments in avalanches down the sides. It was noticed that the underside of descending blocks was often red hot but no molten lava was present at this stage.

At 1 p.m. on the same day a disturbance occurred in a bog about 200 yards to the west of the tholoid, which suggested that a second eruptive centre was developing. A photograph taken by Captain M. T. Scott, Master of the M.V. *Tristania*, shows a great pall of yellowish brown vapour over the region of the bog, contrasting sharply with the white vapour issuing from the summit of the tholoid. The only affect of this disturbance, however, was to discharge mud from the swampy area onto the surrounding grassy slopes and to disgorge boulders at the surface. Two days later, on 12 October, the Commanding Officer of H.M.S. *Leopard* stated: 'Second volcano had ceased erupting, leaving a ploughed field effect of rich black soil over approximately 1000 square yards.' It is likely that this phenomenon was of phreatic origin, occasioned by the rapid vaporization of water at the bottom of the bog as it came into contact with the ascending magma.

On 12 October it was also reported from H.M.S. *Leopard* that the tholoid developed a series of 'blow holes' which appeared to open up one behind the other. These had scarcely any effect on the height of the tholoid on which they were situated, but the debris thrown out broadened the base considerably (figure 58, plate 28).

The tholoid grew swiftly, and on 14 October its height measured from H.M.S. *Leopard* was 240 ft. above the surrounding land (figure 59, plate 28). At this time it was estimated to occupy about 4 acres (15000 sq. yards) as compared with the 142 acres now covered by the volcano and its lava field. During these early stages, 'smoke' was stated to have escaped from a point near the summit on the northern or seaward facing side of the tholoid, and that the locus of emission appeared to migrate progressively southwards. At the same time the tholoid lost its original symmetry and became elongated along its north–south axis. It is possible that the apparent movement of the vapour vent southwards was an impression created solely by the expansion of the tholoid northwards. Reports from H.M.S. *Leopard* relating to 13–14 October, indicate that the first crater was on the site of Diamond Beacon and that the remainder, presumably the 'blow holes', were in a straight line towards the escarpment. The volcano was growing slowly and these reports stated that it might not be long before boulders started reaching the factory and the edge of the Settlement. They also stated that during the day 'No actual lava flow was observed although there was virtually a continuous fall-out of red hot clinker and rock from the summit', but that at night red hot lava was seen streaming down the sides.

On 15 October another report from H.M.S. *Leopard* stated that the volcano was now 'most active' and had attained a height of 250 ft. It was still broadening, and the separate 'blow holes' were now barely distinguishable. Boulders were getting close to the factory which was not considered likely to survive the next few days. It was also said that if the same rate of growth was maintained, houses on the edge of the Settlement would be affected by the end of the following week.

On 21 October, Captain M. T. Scott radioed from the M.V. *Tristania*: 'The main beach of Tristan da Cunha is now almost covered with lava . . . .A stream of lava is also closing in on the first house on the eastern side of the island. The erupting cone is now nearly 400 ft. high . . . .Rocks and lava from the volcano are now nearing the factory.' (See figure 60, plate 28, probably taken on 21 October.) A week later, on 27 October, Captain M. T. Scott reported that the lava had extended 100 yards into the sea where it was steaming vigorously (figure 61, plate 28). The diesel-fuel tanks by the Factory, which had contained 9000 gallons of diesel oil, had blown up, and the Union Jack which had been flying on Julia Point, between the Settlement and the Factory had been 'blasted away or burnt'. Photographs taken at this time by Captain Scott and his officers show lava issuing from the central area of the tholoid and descending down a steep incline to the sea.

It was at about the same time that Captain Klein, Master of the S.S. *Straat Magelhaen*, reported he could see the glow from the volcano 14 miles away at night. He stated also, that a smoke haze hung over the Settlement and that a sulphurous odour could be detected 5 miles out to sea.

Unfortunately, there were no observations of the progress of the activity during November, but on 6 December the Master of the S.S. *Ashbank* reported that the volcano was erupting violently, that the red glow of the lava was visible 20 miles away at night, and that a second crater had formed.

On 16 December, two of the authors (P.G.H. and R.W.LeM.) were aboard H.M.S. *Jaguar* when she visited the island. Although sea conditions did not permit a landing, it was possible to observe the state of activity. They reported (Harris & Le Maitre 1962): 'The original plug or tholoid against the cliff behind Quest Bay had been breached on the seaward side by collapse. Within the small U-shaped caldera formed was a small cone of about the same height, from the summit of which a stream of block lava ran seawards across the area of light grey blocky debris. At about the original shoreline, the lava stream appeared to turn west but its continuation and ultimate end were not visible from the sea.' The height of the volcano was calculated as 480 ft. above sea-level and the height of the cone in the caldera was about 50 to 60 ft. The activity at this time was more violent than any witnessed previously; white vapour, presumably mainly steam, was being emitted from the summit and flanks of the cone, and: 'Every few minutes it puffed forth a cloud of white smoke, accompanied often by an audible bang, and blocks and bombs were thrown 100 ft. into the air. The paroxysms were accompanied by the emission of red flames or liquid 10 ft. or more above the summit.' Calculations based on the expulsion of three blocks with an average diameter of 1 m. indicate an initial velocity of approximately $2{\cdot}4 \times 10^3$ cm/s. and suggest that the energy associated with these paroxysms was of the order of 10^{13} ergs.

About 100 yards behind the cone another crater, situated on the southern edge of the volcanic centre, exploded periodically emitting mushroom-shaped clouds of a yellowish-grey colour in marked contrast to the dense white vapour coming from the central cone. This colour was apparently due to the vast amount of dust these clouds contained, whereas the white vapour from the central cone was virtually free from solid particles. The bursts from the two vents were about equally frequent, but were not obviously connected in any way.

The lava field on 16 December extended 400 yards beyond the former coastline and was about 1000 yards wide at its seaward margin. The eastern part of the lava field, composed of large blocks of a greyish-brown lava, was about 15 ft. above sea-level, whereas the western flow was only about 1 ft. high and was composed of a darker lava, broken into smaller and more jagged fragments. This western flow was steaming profusely along its seaward edge, and during the night of 16 to 17 December it advanced about 20 yards across Little Beach.

Following H.M.S. *Jaguar*'s visit, there was a report from the Master of the S.S. *Crestbank* on 5 January 1962, stating that the first crater was still active, spouting steam and smoke, and on its north-eastern side, brownish lava. The lava front was about 1300 yards wide and steam was escaping in patches. The report also states: 'No second crater sighted, but active crater appears higher to westward than photograph . . . .General impression eruption moderating and no change Settlement.'

No more reports were received until the arrival of the Expedition aboard the S.A.S. *Transvaal* on the 27 January 1962. By this time the intensity of the volcanic activity had greatly diminished, and apart from one or two rather weak puffs of dust from the peripheral vent on 27 and 29 January, it was restricted to the development of a new dome and to fumarolic activity. With the exception of the dome and slight modifications due to marine erosion, the appearance of the parasitic volcano did not alter during the Expedition's stay on the island.

At the end of January the embryonic dome appeared as a slightly elevated ridge trending in a north–south direction along the former course of the lava flows, the highest part being above the breached wall of the inner or central cone (figure 64, plate 29). The period of maximum growth was during the week 6 to 13 February, when the height increased by 29 ft. from 442 ft. to 471 ft. above sea-level. During the following month it grew only another 11 ft. being 482 ft. above sea-level on 19 March just prior to the departure of the Expedition. By any standard the size and rate of growth of the Tristan dome are minimal; the summit dome of Mt. Pelé grew 75 ft. in 1 day and the Turamai dome grew an average of 40 ft. per day over a period of 2 weeks (Williams 1932).

At the beginning of February when the construction of the dome was proceeding at its maximum rate, numerous avalanches swept down its flanks, accompanied by clouds of dust and glowing blocks. At night, open cracks could be seen on the sides of the dome, a red glow emanating from within. The avalanches and the cracks were presumably an expression of the pressure exerted by the confined lava on the inner walls of the carapace.

No explosive manifestations accompanied the dome building on Tristan as they did on Mt. Pelé, Bogoslof (Williams 1932) and other volcanic domes.

On 8 March, immobile red-hot rock was visible in a fracture on the summit of the dome, about 8 ft. below the surface; with the aid of an optical pyrometer and a thermocouple the temperature was determined as 890 °C. The air temperature immediately above the dome was 35 °C. The only other instance when red hot material was closely examined was during the middle of February on the western lava flow about 40 yards to the west of the flag pole where, for two or three nights, a red glow was seen in two small cracks about 10 yards apart.

Fumarolic activity declined throughout February and March and although the vicinity of the central cone remained the chief fumarolic area, the quantity of vapour escaping was very much reduced. Thin columns of vapour continued to issue from a scattering of fumaroles on the lava field.

4. Morphology of the 1961 eruptive centre

4·1. *General form*

The source region and the lava field comprise the two main units of this parasitic volcano (see figure 19 and figure 20, plate 16). The former is bounded by a horse-shoe-shaped ridge which dips northwards at about 15° and opens seawards onto the lava field. This ridge is the outermost remnant of the initial tholoid, the central portion of which underwent a marked subsidence at the time of the outflow of the first lava. Within the large depressed area so formed, the central cone rises to a height of 450 ft. above sea-level. Cutting the northern wall of the cone and trailing seawards is the dome. Neither the central cone nor the dome is at any point contiguous with the outer ridge from which they are separated by an arcuate trench or fosse, analogous with the fosse which separates Castles Peak dome from the walls of English's Crater in Montserrat (MacGregor 1938). A second, peripheral crater lies astride the most southerly part of the outer ridge where this abuts against the foot of the Main Cliffs.

The seaward inclination of the land surface on which the new centre developed was approximately 10° and the subsequent form of the volcano and its lava field was probably governed to a large extent by the slope of this terrain. The maximum width of the lava field is 1200 yards and its greatest extension in a north-south direction is approximately 1000 yards. The width of the source region in which the craters are situated is 350 yards. The total area covered by the products of the eruption is about 700 000 square yards, two-thirds of which lie beyond the former coastline (see figure 19). The total volume of the volcanic products is estimated at 26 million cubic yards, 17 million of which are represented by the lava field.

The location and nomenclature of the principal features of the parasitic volcano are shown in figure 19, Each of these features will now be described separately.

4·2. *The initial tholoid*

The outermost slopes of the parasitic volcano dip away from the summit of the arcuate ridge that forms the principal relic of the tholoid at between 35 and 40°. They are composed of a fragmentary admixture of new blocky lava, ash and older accidental material

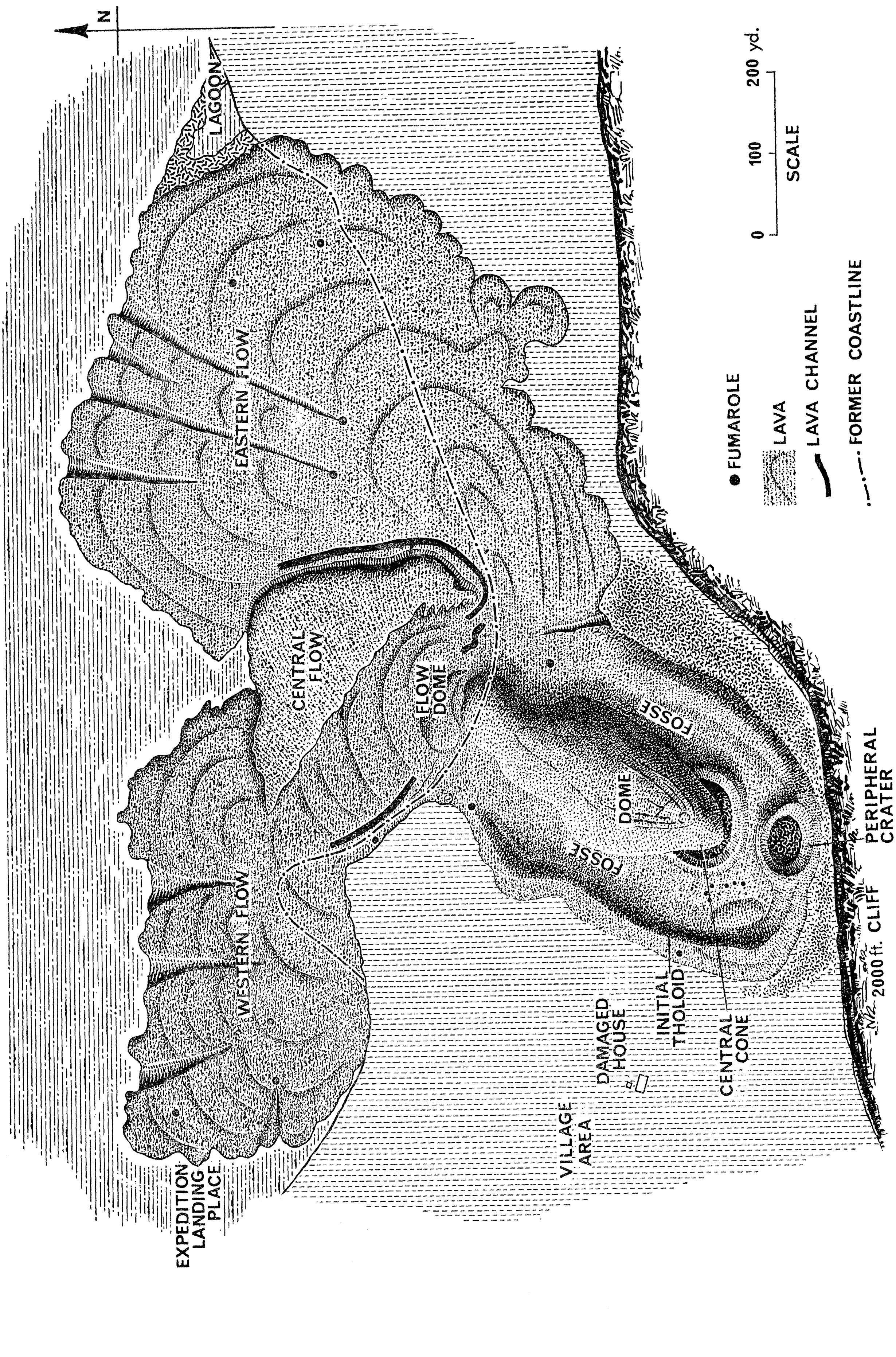

FIGURE 19. The 1961 eruptive centre.

FIGURE 20. The 1961 Eruptive Centre from the top of the Main Cliffs.

from the Settlement plain talus pushed up to the surface by the rising tholoid. Most conspicuous amongst this accidental material are blocks of a coarse yellow tuff similar to that cropping out low in the Main Cliffs behind. Blocks of a pale-grey, crystalline lava are particularly abundant on the south-western flank of the tholoid. None of the accidental blocks possessed a coating of fresh lava; this suggests that they did not come into contact with the magma. The fresh lava of the tholoid is medium grey in colour but exposed surfaces have a rough, brittle, pale yellow-brown crust.

The highest point of the tholoid (447 ft.) is formed by a tapering jagged pinnacle that rises above the south-western rim. It possesses a marked vertical jointing, and lower crags of a similar nature cluster around it. Although its form is somewhat suggestive of a protruded spine, it is more likely that this feature is a relic of the crust of the tholoid fortuitously preserved in its present position after the collapse of the central area. Several fumaroles occurred in the vicinity of these crags, and one on the outer slopes about 100 ft. below the highest point of the rim was intermittently active.

4·3. *The fosse*

Immediately within and below the rampart formed by the tholoid ridge is the horse-shoe-shaped ditch or fosse bounded on its inner side by the flanks of the central cone and the dome. The form of the fosse varies; to the south, near the peripheral crater, it has a broad, flat floor; the western limb is deeper, near V-shaped in cross-section, whilst to the east of the central cone it is generally broad and shallow. Northwards, along both its arms, the fosse gradually loses its identity, merging into a talus slope on the lava field. Beneath this talus on the eastern side, the Factory lies buried, its approximate position being marked by a prominent fumarole; fumaroles occurred elsewhere in the fosse, especially on the floor of the southern section. Rock falls from the dome were slowly infilling the fosse throughout February and March 1962, but it is now unlikely that the feature will become completely obscured as the dome has stopped expanding.

4·4. *The central cone*

It is from a vent within the central cone that almost all the products of the eruption are believed to have been derived. The cone itself is of pyroclastic origin though principally composed of blocks of lava rather than scoria or cinders; these blocks were probably formed by the explosive fragmentation of part of the initial tholoid (figure 63, plate 29).

The cone has a basal diameter of about 80 yards and rises approximately 50 ft. above the fosse and 450 ft. above sea-level. It has a steep outer slope and a jagged rim of pinnacles of reddish blocky lava and less conspicuous scoria, divided by gaping fissures. As the development of these fissures was coincident with the maximum growth of the dome, it would appear that the tension induced by the rising dome was responsible in part for the rupturing of the walls of the cone. Though the material of the cone is mainly reddish, colour variety is provided by encrustations of solfataric minerals. The floor of the crater is littered with blocks of all sizes, many of them, undoubtedly, having been derived from the southern flanks of the dome. The north wall of the cone was breached by lava flows, but this gap has been blocked by the growth of the dome. Fumarolic activity was stronger and more persistent at this crater than at any other position on the entire eruptive centre.

4·5. *The peripheral crater*

Situated astride the tholoid ridge at its southernmost point, the peripheral crater is approximately 35 yards in diameter across the rim and 25 ft. deep. Its inner walls are steeply inclined to an irregular floor covered with blocks of a rather spongy lava. About 2 ft. below the rim of the crater is a corona of fumaroles whose position is emphasized by pale-yellow solfataric deposits. The cinders and ash which constitute the gentle outer slopes of this crater were evidently of insufficient quantity to build a feature of any consequence. Solfataric exhalations were particularly strong on the north-western slopes where the surface is cut by innumerable small radial fractures and where the cinders are coated with crystals of sulphur, gypsum, etc.

4·6. *The dome*

The dome is roughly oval in plan, with maximum dimensions of 320 yards and 135 yards; these dimensions include the talus slopes that form an apron of debris around it. The highest point occurs immediately above the breached inner cone, from where the axis pitches north-north-eastwards along the path of the previous lava flows. The slope along the crest of the dome is steepest in the immediate vicinity of the summit. The major joint direction runs parallel to the long axis of the dome (see figure 19) and the joint surfaces are conspicuously convex outwards. Along these joint planes, layer after layer of the carapace was peeling off in a manner comparable to exfoliation on a grand scale (figure 65, plate 29). Individual sheets would stand some 6 ft. clear of the dome as flanking, near vertical, slightly convex walls. The surfaces of these walls are rough and often adorned with sharp dentate plications whilst broad slickensides are sometimes gouged across them, inclined seawards parallel with the crest of the dome.

The dorsal surface of the dome is a chaotic accumulation of blocks and slabs of lava up to several metres in diameter and often precariously balanced one upon the other. Towards the summit of the dome, where the slope steepens, the surface is dissected by fractures and chasms; the longer chasms, which are sometimes as much as 20 ft. deep and 4 ft. across and are linked by smaller cross fractures, follow the trend of the dome and converge towards the summit. Distinct from the fractures are wider and shallower troughs which are also elongated along the principal axis of the dome. One of these features, situated about 100 ft. SSE of the summit, has arcuate vertical walls about 12 ft. high on its southern side and is open to the north, where its floor intersects the surface of the dome. It is believed that this and similar features are the result of the collapse of a segment of the dome between tension fractures. In every case the hinge is on the northern side and the maximum movement is on the southern side, where tension and instability were greater during the development of the dome.

The elongation of the dome along the former course of the lava flows is not considered to be due to the squeezing up of viscous lava along the channel, in the manner of similar structures described by Nicols (1938) on the McCarty's flow, New Mexico. Assuming that the vent which fed the dome is the one from which the lava flows previously escaped, and there is no reason for believing otherwise, then the dome is asymmetrically disposed with respect to its conduit. As the elongation is downslope, there is thus a strong suggestion that the viscous, dome-lava flowed slightly and constructed a tapering coulée. Having built a shell of this form, fresh lava may have continued to well up from the conduit and to migrate slowly downhill in a tunnel in the tail of the coulée. This was probably the situation at the end of January. When further lateral movement was prohibited by the confining pressure of the thick carapace and possibly by the increased viscosity of the magma, growth was directed upwards and restricted to the area immediately over the vent. Hence, the rapid development of the summit region during the first half of February. The growth of the dome may be regarded as virtually entirely endogenous, though it is by no means inconceivable that in its embryonic condition, when the carapace was thin and the lava more fluid, that subsidiary exogenous growth may have occurred. Daly (1925) refers to a steeply inclined trachyte dome on Ascension whose form and origin appear to be analogous to this structure. It is notable that though domes are a relatively common feature on most of the islands on the Mid-Atlantic Ridge, they are rare on Tristan.

4·7. *The lava field*

Three separate flows may be distinguished on the basis of differences in their geographical position, their time of emission and to a lesser extent on physical differences in the nature of the lava (see figure 19).

4·7·1. *The central flow*

This was the first flow to be emitted from the new eruptive centre and was responsible for the obliteration of the Factory. It is known to have developed from a northward distension of the initial tholoid, and to have advanced slowly down the steepest slope to the sea. In character it is a block or slab lava as defined by Finch (1943), composed for the most part of large, generally smooth, polygonal blocks, a few of which have a rough khaki crust; the average size of these blocks is considerably larger than those on the later flows. The crescent of large, upturned slabs of lava which made a distinctive feature along the northern limit of the flow, probably represents part of the northern wall of the tholoid. On the seaward side of these pinnacles vertical cliffs, 40 ft. or more in height, overlook the western lava which has flowed around their base. Only the seaward, distal margin of the flow is visible; the remainder has been obscured by the passage of the two subsequent flows across it. The eastern margin of the central flow is separated by a deep valley of talus from the later, eastern flow whilst the western flow covers the other flank.

4·7·2. *The eastern flow*

The second lava followed the same course as its predecessor down the steep incline to the position of the former coastline, then diverged to swing eastwards across Big Beach towards Pigbite and extended seawards in a series of lobes. Concentric and radial elements preserved on the lava field testify to the manner of its development. Low concentric ridges of *aa* represent successive fronts of the advancing lava and are thus normal to the direction of flow which was, in general, north-north-eastwards (see figure 19). The principal exception is seen at the southernmost edge of the flow, where the closely spaced concentric ridges suggest that movement was in a southerly direction. These anomalous ridges were probably formed at a late stage, after most of the eastern flow had been extruded. A sudden increase in the volume of lava emitted from the vent and constriction downstream, brought about by the solidification of much of the earlier material, probably caused the fresh lava to break through southwards, albeit against the gradient of the underlying terrain. Where the flow crosses Big Beach innumerable small lobes and ridges have pushed onto the sand and make a highly irregular boundary. These are marginal flow-lobes squeezed out at right angles to the principal flow direction as solidification at the front inhibited further forward movement thus causing piecemeal lateral migration onto Big Beach where the flat sand offered little resistance.

The principal radial elements are the pronounced valleys of the distal region, which are sometimes as much as 400 yards long. Beginning abruptly, often with a fumarole at their head, they have rubbly blocky sides and are relatively straight, flaring slightly at their seaward end where they terminate in small beaches or incipient bays. These valleys are the boundaries between individual tongues of lava which pushed seawards one after the other, with each new tongue being diverted to one side by the talus slope of its predecessor. Some of the larger tongues bifurcate near the seaward margin.

The nature of this flow is rather different from that of the central flow. It is an *aa* lava consisting entirely of loose amorphous blocks with sharp spiny surfaces. Where the blocks have been abraded against each other during movement, the rough jagged surfaces have given way to featureless powdery scars. Situated towards the eastern side of the flow are a few hornitos, in the form of heaps of *aa* lava encrusted with solfataric deposits, through which wisps of vapour were quietly escaping.

4·7·3. *The western flow*

This was the last flow to form and is very similar in character to the eastern flow, showing the same types of concentric ridges and radial valleys, with a few scattered fumaroles. The lava itself is dark rubbly *aa* with rough surfaces except where they have been abraded. One of the most notable features of the western flow is the conspicuous lava channel found close to and parallel to the western edge of the lava field (Baker & Harris 1963).

4·7·4. *The flow dome*

At the point where the lava flows diverge from the eruptive centre, roughly on the site of the former coastline, is a low, rounded, blocky feature about 60 yards in diameter and 30 ft. high. It has been formed on the western flow and developed in the interval between the cessation of the lava flows and the growth of the dome for it was clearly visible at the end of January. This structure is probably a flow dome, formed when the lava was becoming very viscous, and though capable of moving down the steep incline from the vent accumulated into this feature where the gradient diminished. The lava which comprises the flow dome is of the same blocky nature as that of the dome and the central flow. A thin tongue of identical material extends about 100 yards from the north-western foot of the flow dome across the darker *aa* lava of the western flow, indicating that only an insignificant volume of material was at this stage sufficiently mobile to evade incorporation within the dome.

5. Petrography

5·1. *General statement*

Each of the analyzed specimens from the new eruptive centre has a composition of trachyandesite; this chemical similarity is paralleled by a relatively constant mineral assemblage. The modal analyses in table 18 of specimens from different units of the parasitic volcano illustrate the limited mineralogical variation.

Table 18

	initial tholoid	lava flows	dome
plagioclase	29·0	28·2	28·8
pyroxene	4·7	7·6	6·4
amphibole	2·3	2·1	1·5
ore	2·6	4·0	4·1
groundmass	61·4	58·1	59·2
no. of points counted	3319	4597	5271

The material of the initial tholoid, the dome and the central flow has a rough, slightly green or pale khaki crust, whilst the smaller blocks of the remaining lava flows have black spiny crusts. These superficial differences, however, conceal a uniformity which becomes apparent when specimens from the interior of each of the units are compared. In each case the hand specimen is a medium-grey, finely vesicular rock showing occasional short prismatic crystals of plagioclase and elongate amphibole in an aphanitic base.

In thin section, the rock exhibits a fluidal texture, showing sporadic large phenocrysts of plagioclase, clinopyroxene and basaltic hornblende together with microphenocrysts of plagioclase and pyroxene in a microcrystalline to glassy groundmass.

The large plagioclase phenocrysts, which reach 2 mm in diameter, have a large core of basic labradorite (*ca.* An_{68}) enclosed by a narrow, sensitively zoned rim ranging in composition to sodic andesine. Oscillatory zoning frequently occurs in this border zone; for example, the following variation was recorded in a large plagioclase phenocryst from the central flow (614): core, An_{68}; rim, An_{49}–An_{40}–An_{49}–An_{40}. Characteristic of these larger plagioclases is a strongly corroded core containing a cellular structure of brownish glass and inclusions of ore and pyroxene. The abundant plagioclase microphenocrysts, averaging about 0·4 mm in length, have a large clear core of labradorite (*ca.* An_{58}) surrounded by a narrow zoned border ranging outward to An_{40}. Both the large and small phenocrysts of plagioclase are sometimes enclosed by a very narrow rim of alkali feldspar (?).

Large phenocrysts of clinopyroxene, up to 1·5 mm in diameter, occur infrequently and often poikilitically enclose small plagioclase laths and granules of ore. These crystals have a core which is pleochroic from a grass-green to a yellowish-green, has a small extinction angle ($\gamma \wedge c$ less than 20°) and is optically positive and with a $2V$ of approximately 70°; it is apparently aegirine-augite. The wide border that envelops the aegirine-augite is a pinkish-brown pyroxene with a $2V$ of approximately 60°; it is probably a titanaugite. The pyroxene microphenocrysts, whose average size is about 0·3 mm are brownish-green or grey-green in ordinary light and are strongly zoned. Their refractive index (β) is $1{\cdot}723 \pm 0{\cdot}002$ and the $2V$ ranges from 65° at the core to 54° at the rim.

Phenocrysts of a strongly coloured amphibole range from about 4 to 0·1 mm in length. Optically negative with a $2V$ of 70°–75° they have a small extinction angle ($\gamma \wedge c$ *ca.* 3°). The pleochroism is somewhat varied but in general approximates to the following formula: X, straw-yellow; Y, brown; Z, deep brown to reddish-brown. Invariably, the amphibole shows some degree of resorption expressed in the presence of a corona of granular ore. The resorption is not always restricted to the rim; many of the larger crystals have a small resorbed core and others show two distinct zones of resorption separated by unaltered amphibole. The composition of the amphibole cannot be determined from the optical data but properties conform with those of basaltic hornblende. However, in view of the titanium in the rock, as indicated by the rock analyses and the presence of sphene and ilmenite, it is not unlikely that the amphiboles may approach kaersutite in composition.

The ore, which occurs abundantly, sometimes as phenocrysts up to 1 mm in diameter, appears to be predominantly ilmenite.

One of the most striking constituents in some of the specimens is an isotropic, sky-blue mineral which occurs as scattered discrete grains usually of the order of 0·03 mm in diameter. It has a very erratic distribution, being common in some specimens and absent in others. It is sometimes rounded in outline and appears to fill cavities, suggesting a late formation (figure 80, plate 32). Both these factors point to an association of this mineral with the release of volatiles which were concentrated in restricted areas; on X-ray analysis the mineral proved to be haüyne.

Leucite occurs in the new lava in very minor amounts. Its development is extremely sporadic not only from one part of the lava to another but also within a single specimen. Unlike all the other occurrences of leucite on Tristan, so far examined, it does not occur interstitially although it is confined to the groundmass where it occurs as very small rounded grains up to 0·05 mm in diameter typically containing tangentially arranged rods of pale-green pyroxene (see figure 81, plate 32). It is virtually isotropic and no polysynthetic twinning was seen with any certainty. The leucite figured by Edwards (1938, Fig. 2, Plate VII) in a leucite tephrite from Kerguelen is almost identical in appearance. Concentrations of the light fraction (2·62 g/cm^3) of two specimens of the new lava were X-rayed and the powder photographs consisted almost entirely of leucite lines thus confirming the identification.

The extent to which the petrography of individual units of the new eruptive centre deviates from the preceding general description is discussed below.

5·2. *The initial tholoid*

The exposed surface of specimens from the tholoid is usually yellow whilst the centre is medium-grey; marginal to the surface, bands of these two colours interdigitate. The grey bands are more vesicular than the yellow and in thin section are seen to have a brown glassy base whereas the lighter bands have a slightly birefringent, more feldspathic matrix.

The porphyritic constituents are plagioclase and basaltic hornblende and the microphenocrysts are plagioclase, aegirine-augite and sphene. The clinopyroxene sometimes shows a bright-green core with a yellow-green to brown-green border, but usually the smaller prismatic crystals are a strong yellow-green colour and have a maximum extinction angle ($\gamma \wedge c$) of approximately 26°. The pyroxene microphenocrysts of the dome and the lavas do not show such powerful colouring and it is possible that the earliest pyroxenes were richest in the aegirine molecule. Crystals of sphene, having characteristic strong birefringence and typical rhomboidal cross section, are present. Occasional xenocrystic clots of plagioclase, biotite and sphene are found in specimens from the tholoid.

5·3. *The lava flows*

The pyroxene microphenocrysts of the lavas are greyish-green in colour rather than the yellow-green of those of the initial tholoid, and have a maximum extinction angle ($\gamma \wedge c$) of approximately 36°. The groundmass of the lavas appears to contain a higher proportion of dusty ore than is found in that of the tholoid or dome. The western flow shows pyroxene phenocrysts with cores of a very intense green and distinct borders of pinkish brown augite. Large sphenes are more prominent in the Western flow.

5·4. *The dome*

In general, specimens from the dome are more crystalline than those from elsewhere, and are inclined to be seriate rather than porphyritic. For instance, ore in the lavas is disseminated throughout as tiny granules whilst in specimens from the dome it forms larger and fewer crystals. Similarly, the pyroxene microphenocrysts tend to be larger than in the lavas, which is doubtless an indication of their more prolonged period of crystallization. Slaty grey-green in colour, they have a maximum extinction angle ($\gamma \wedge c$) of 38°. Large phenocrysts of pyroxene are the same as found in the other units, with a green core of aegirine-augite and a brownish rim, which is probably titaniferous augite. One of these aegirine-augite crystals was found in close association with a large plagioclase, ore and sphene, suggesting a xenocrystic origin. The largest haüyne crystal found occurred in a specimen from the east flank of the dome (656); with a diameter of 0·3 mm, it is slightly rounded, bright blue at the rim and colourless in the centre. Clots of coarse minerals which appear to be of xenocrystic origin show the following mineral assemblages: (i) plagioclase–hornblende–apatite; (ii) plagioclase–pyroxene–sphene–apatite–ore; (iii) plagioclase–pyroxene–ore (figure 79, plate 31).

5·5. *Volcanic bombs*

The bombs possess highly vesicular, scoriaceous crusts and an interior that is sometimes banded with alternating black glassy and dark crystalline layers. A thin section of one of the bombs (22) showed phenocrysts of plagioclase, clinopyroxene and basaltic hornblende in a predominantly glassy groundmass. The occasional large crystals of plagioclase, in common with those from other parts of the eruptive centre, show a network of glassy material at the core. The plagioclase microphenocrysts are slightly zoned and have a core of composition *ca.* An_{55}. The basaltic hornblende is pleochroic from a deep-brown (Z) to a pale yellowish-brown (Y). Unlike the hornblende from elsewhere, none of these crystals has a resorbed rim or a corona of iron ore. The amphibole is somewhat more abundant in the bomb than in the specimens from the initial tholoid, lava field and the dome. Occasional phenocrysts of bright green aegirine-augite rimmed with a pale, slaty-green pyroxene occur. The pyroxene microphenocrysts are grey-green, of prismatic habit with a maximum extinction angle ($\gamma \wedge c$) of approximately 38°. Crystals of ilmenite up to about 0·2 mm in diameter are common whilst there is no trace of haüyne. The groundmass consists of plagioclase and pyroxene microlites in a brownish glassy base.

5·6. *Ash*

The ash from the eastern side of the centre is very well sorted, with a median grain size of between 0·5 and 0·25 mm. The sorting is probably accounted for by the winnowing effect of the strong winds. Consisting in part of discrete crystals and in part of consolidated rock fragments, the ash has a mineralogical assemblage closely comparable with that of the lavas; namely, plagioclase (*ca.* An_{40}) clinopyroxene, basaltic hornblende, ore and glass. The pyroxenes are generally grey-green but occasional bright green crystals do occur. The amphibole is pleochroic from a pale yellowish-brown (X) to a deep brown (Z), and as in the bomb it shows no trace of resorption.

5·7. *Coarse-grained xenoliths*

A few very small plutonic xenoliths were obtained from various parts of the dome and the lava field and found to contain the following mineral assemblage: plagioclase, olivine, clinopyroxene, amphibole, biotite, ore, apatite and sphene. Though the four xenoliths examined are very small, the following modal analysis gives an approximate indication of the relative abundance of the minerals present (table 19).

TABLE 19

spec. no. ...	645	510	519	509	av.
plagioclase	62	60	46	45	56
olivine	1	0	0	0	—
pyroxene	25	16	6	3	14
hornblende	7	0	1	4	5
biotite	0	16	33	33	15
ore	4	6	9	10	7
apatite	1	2	5	5	3

It would appear that there is a sympathetic decrease of plagioclase with decreasing pyroxene, and at the same time an increase of ore and apatite. The pyroxene is in antipathetic relation to the hornblende and biotite and in some specimens is seen in various stages of conversion to amphibole. Olivine is only present in the specimen with the highest pyroxene content (645). In the hand specimen the xenoliths have a gabbroic aspect and a granular texture; in only one instance (519) was there any conspicuous preferred orientation of the crystals. Feldspar, biotite, hornblende and pyroxene may be distinguished in the hand specimen and in specimen 645 small olivines could be identified.

Under the microscope it can be seen that there are some unzoned plagioclases with a composition of about An_{75} whilst others are strongly zoned from a core of about An_{65} and a rim of An_{45}. In only one of the specimens (645) does the plagioclase exhibit a cellular glassy structure, at the core in some crystals and as a border in others. Occasionally the plagioclase crystals have a smooth rounded outline indicative of slight magmatic corrosion. A thin film of vesicular glass often surrounds these and other crystals.

The clinopyroxenes are strongly coloured an olive or grey-green, though some show pleochroism from this to a pale brownish-green (X). They have a $2V$ of 63° and inclusions of ore are common. In specimen 645 much of the pyroxene shows a patchy conversion to an orange-brown amphibole.

The amphibole occurs as subhedral, platy crystals, with no trace of resorption. It is strongly pleochroic from a very dark-brown (Z) to a pale, slightly brownish-yellow, has an extinction angle ($\gamma \wedge c$) of up to 13°, and would appear to be principally basaltic hornblende.

Individual biotite crystals are as much as 4 mm long and have a small extinction angle (4°). Pleochroism is strong, from a deep, red-brown to a pale yellowish-brown. In some specimens the biotite is strongly oxidized, being almost opaque with a deep red margin. Sometimes of a skeletal habit, the ore often appears as large crystals about 1 mm in diameter. Granules and trains of ore are found in the ferromagnesian minerals. In reflected light white flecks, probably leucoxene, suggest that it is mostly ilmenite.

Apatite is remarkably abundant in some specimens occurring poikilitically within plagioclase, pyroxene and amphibole crystals, and as fairly large rounded crystals at the junction of several plagioclases or ferromagnesian crystals. Occasional rather rounded sphenes with typically high interference colours are seen in some specimens.

These coarse grained xenoliths bear a strong mineralogical resemblance to those found at many other localities on the island (pp. 501–502).

6. Fumarolic minerals

Fumarolic minerals were developed extensively in and around the small peripheral crater; although all the material described below came from this locality, similar minerals were also found in minor amounts at numerous other localities scattered over the dome and lava field.

Seen *en masse* the colour ranges from grey through white to yellow and orange. In habit they vary from distinct crystalline masses to amorphous-looking, sometimes deliquescent encrustations often warty in appearance. The minerals are deposited on blocks of the lava, the surface of which is often bleached completely white. This bleached layer consists of remnant feldspar and isotropic material, probably amorphous silica. An identical effect was produced on a piece of the new trachyandesite lava by subjecting it to HF fumes over a water-bath for about 8 hours. On some specimens a grit is present consisting of grains of bleached trachyandesite, crystalline aggregates of anhydrite, gypsum and fluorite (?), together with some single crystals of gypsum, bassanite and sulphur. The encrustations tend to be heterogeneous in character which makes correlation between optical, microchemical and X-ray work difficult.

The following list of minerals have been identified after a preliminary examination No claim to completeness is made for this list and in all probability further work will reveal the presence of additional mineral species. Optical identifications were based on Larsen & Berman (1934), and Palache, Berman & Frondel (1951), the latter hereafter being referred to as 'Dana 7th'.

6·1. *Sulphates*

Gypsum [$CaSO_4 . 2H_2O$] occurs as massive crystalline layers up to 5 mm thick and also as free standing blade-like crystals up to 5 mm long and 1 mm wide. It is usually colourless but on some specimens is stained yellow and orange (e.g. 532) and is commonly associated with anhydrite in an intimate crystalline mixture. Verified by optics and X-ray powder photographs.

Anhydrite [$CaSO_4$] was found as massive, coarse to fine, crystalline material, as thin transparent basal plates up to 0·5 mm across and as a sugary matrix when associated with gypsum. Varieties range from colourless to white and translucent to transparent, whilst in some specimens it is stained yellow (e.g. 542). Verified by optics and X-ray powder photographs.

Bassanite [$CaSO_4 . \frac{1}{2}H_2O$] occurs as rosettes of white opaque acicular needles up to 1 mm long and also as obvious pseudomorphs after needles of gypsum. Good cleavage flakes giving straight extinction with $\alpha' = 1{\cdot}544 \pm 0{\cdot}002$ and $\gamma' = 1{\cdot}558 \pm 0{\cdot}002$ and either a B_{x_o} or flash figure.

Alum [$KAl(SO_4)_2 . 12H_2O$] is present as grey amorphous-looking coating associated with ralstonite and as thin layers between gypsum cleavages. It is often slightly cloudy. $1{\cdot}446 < n < 1{\cdot}464$. Confirmed by X-ray powder photograph.

? *Mirabilite* [$Na_2SO_4 . 10H_2O$] was not seen optically but thought to be present with halite and an unknown mineral in an X-ray powder photograph of a bright orange encrustation associated with erythrosiderite on specimen 540.

Louderbackite [$Fe^{2+}(Fe^{3+},Al)_2(SO_4)_4 . 12H_2O$] occurs associated with tincalconite (?) in colourless crystalline centres of slightly brownish globular encrustations on specimen 533. It has a fibrous to platy habit with good cleavage, straight extinction, $\alpha = 1{\cdot}548 \pm 0{\cdot}003$, $\beta = 1{\cdot}556 \pm 0{\cdot}003$, $\gamma = 1{\cdot}590 \pm 0{\cdot}006$, is biaxial positive, $2V \doteqdot 50°$. Positive microchemical tests for SO_4, Fe^{2+} and Fe^{3+}. Not previously recorded as a natural (volcanic) fumarolic mineral.

Metavoltine [$KNa_3Fe_3^{3+}(SO_4)_6OH . 10H_2O$] occurs as a very thin (0·025 mm) orange-brown crust on warty surface of specimen 540. It has a good basal cleavage and is faintly pleochroic in tones of pale-yellow. Uniaxial negative $\epsilon = 1{\cdot}590 \pm 0{\cdot}003$, $\omega = 1{\cdot}580 \pm 0{\cdot}003$.

Jarosite [$KFe_3^{3+}(SO_4)_2(OH)_6$] was not detected with any certainty optically but identified in an X-ray powder photograph of a yellow-brown crust beneath some sulphur crystals on specimen 531. The crystals comprising the crust are very small, yellow in colour with a high birefringence and refractive indices (n) $\lesssim 1{\cdot}740$.

An unidentified sulphate with the following properties occurs as a soft, white, very finely crystalline crust on top of gypsum on specimen 531. Optical data include: $\alpha = 1{\cdot}457 \pm 0{\cdot}005$, $\gamma = 1{\cdot}478 \pm 0{\cdot}003$, biaxial positive, medium to large $2V$. The presence of K and SO_3 was revealed by positive microchemical tests and the material is soluble in H_2O. From the optics this material could be picromerite, aluminite, mercallite, alunogen, or tamarugite. X-ray investigation is pending.

6·2. *Fluorides*

? *Fluorite* [CaF_2], an isotropic material with the optics of fluorite, occurs with gypsum and anhydrite in pinkish-brown rounded grains and also as a massive brownish coating. The refractive index is slightly variable ranging from $n = 1{\cdot}433 \pm 0{\cdot}003$ to $1{\cdot}438 \pm 0{\cdot}003$.

? *Cryolite* [Na_3AlF_6]. An anisotropic mineral which could be cryolite from the optical data occurs in the yellow warty crust on specimens 534 and 540 intermixed with hieratite and another isotropic mineral similar in properties to an unnamed mineral of Naboko (see below). Optical data include: biaxial positive with medium $2V$, refractive indices less than 1·362 but slightly greater than 1·330, birefringence weak, and sector twinning occurs in some crystals; from these data the mineral could also be weberite [Na_2MgAlF_7]. As neither of these minerals has been reported from a fumarolic paragenesis their confirmation would be of great interest.

Ralstonite [$Na_{3-x}(Al,Mg)_{16}(F,OH)_{48}.7H_2O$ with $x \doteqdot 0·3$] occurs in yellow warty crusts associated with halite, hieratite and cryolite (?) in specimen 540. Positive identification was by X-ray powder photographs as optical identification was unsatisfactory owing to variability of the refractive index.

? *Thomsenolite* [$NaCaAlF_6.H_2O$] is present as small crystals up to 0·02 mm long occurring with hieratite and cryptohalite in a pale-yellow, glazed-looking encrustation on specimen 532. It is biaxial negative with a medium to small $2V$; $\alpha = 1·407 \pm 0·004$, $\gamma = 1·423 \pm 0·004$. This mineral has not been previously recorded in a fumarolic occurrence. It is possible that the mineral is ralstonite which has also been recorded as biaxial negative, $\alpha = 1·411$ (Dana 7th, 2·127).

? *Unamed mineral of Naboko* [$NaCaMgAl_3F_{14}.4H_2O$] Dana 7th, 2·127. Material similar to that described by Naboko from Klyuchevsky volcano, Kamchatka, U.S.S.R., occurs as a very pale-yellow, turbid, isotropic mineral with a refractive index (n) of $1·382 \pm 0·005$ in yellow warty encrustations (531, 533 and 534) and in a white vitreous crust (532). It is associated with tincalconite (?), cryolite (?), hieratite, alum and ralstonite.

Hieratite [K_2SiF_6] occurs in yellow warty crusts closely associated with cryptohalite, ralstonite, halite and cryolite (?). It is isotropic with a refractive index of $1·330 < n < 1·350$. Identification was confirmed by X-ray powder photograph.

Cryptohalite [$(NH_4)_2SiF_6$] occurs in yellow warty crusts where it is closely associated with hieratite. It is isotropic; $1·362 < n < 1·371$. The presence of NH_3 was confirmed by microchemical tests.

6·3. *Chlorides*

Halite [NaCl] was found in yellow warty crusts where it occurred with hieratite and ralstonite. This mineral was initially identified by X-ray powder photographs which showed it to be in very finely divided particles.

Erythrosiderite [$K_2FeCl_5.H_2O$] is present as very small (0·025 mm), bright orange crystals on a warty crust of halite (540); it is closely associated with metavoltine. Optical data: biaxaial positive, medium to large $2V$ (in some crystals almost 90°), $\alpha = 1·720 \pm 0·005$, β just greater than 1·740, γ less than 1·81. The mineral is highly soluble in H_2O; K and Cl confirmed by microchemical tests.

6·4. *Carbonates*

Natron [$Na_2CO_3.10H_2O$] occurs as yellow to white deliquescent globular encrustation resting on tincalconite (?) and louderbackite (533). It is very finely crystalline; average size 0·01 mm by 0·001 mm and has refractive indices of $\alpha = 1·407 \pm 0·004$ and $\gamma = 1·430 \pm 0·004$. Lamellar twinning is common in large crystals, the angle between α' and the composition plane being approximately 20°. The faint yellow colour of this mineral is bleached by low refractive index organic liquids; it is extremely soluble in H_2O, and Na and CO_2 were proved by microchemical tests.

6·5. *Borates*

? *Tincalconite* [$Na_2B_4O_7 . 5H_2O$]. Material with the optics of tincalconite occurs as a colourless crystalline mass underlying yellow-brown warty encrustations on specimen 533. The mineral is uniaxial positive (occasional crystals are anomolously biaxial with $2V$ up to 5°), $\omega = 1{\cdot}466 \pm 0{\cdot}004$, $\epsilon = 1{\cdot}486 \pm 0{\cdot}004$ and has a basal tabular habit. It is slowly soluble in H_2O and Na and B were confirmed by microchemical tests. X-ray powder photographs of this material do not appear to correspond with those of tincalconite (based on A.S.T.M. data card 8-49).

6·6. *Elements*

Sulphur [S] occurs abundantly in a variety of habits; acute pyramids, thin plates, barbed crystals and rounded recrystallized globular masses; the crystal faces are commonly etched. It tends to be associated with gypsum and anhydrite and only rarely with the warty encrustations.

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APPENDIX I. THE BIOLOGICAL WORK OF THE EXPEDITION

(a) Introduction

By M. W. Holdgate, *British Antarctic Survey*

The biologists of the Royal Society Tristan da Cunha Expedition were assigned four main tasks by the Expedition Committee and the World Wild Life Fund which sponsored them. Their first duty was to assess the direct effects of the eruption upon the flora and fauna. Secondly, they were to consider the indirect effects resulting from the evacuation of the human population and the consequent decontrol of introduced grazing mammals, predators, and alien invertebrate pests. Thirdly, they were asked to formulate long-term conservation measures so the the native ecosystem would not be irremediably devasted by these uncontrolled alien species. Finally, they were instructed to make what contribution they could to the overall knowledge of the flora and fauna of the Tristan group by making general collections and ecological observations.

The Royal Society Southern Zones Expeditions Committee noted that the full appraisal of the biological results of the Expedition will only be possible if they are set in context by general review papers summarizing the present state of knowledge of the land flora and fauna of the Tristan group as a whole. Such general reviews are currently in preparation, and will be published together with the full biological results of the Expedition, elsewhere. In this appendix those sections of the biological results which are directly relevant to the new volcano and its effects are presented in abstract; it is hoped that the full report and background reviews will be made available shortly.

It was originally supposed that the eruption might have far-reaching effects upon the fauna and flora of the island, either by direct destruction or by the permanent cessation of men's habitation. In fact the area of destruction remained very small and therefore did not materially affect the biota, whilst the absence of human beings has proved not more than a temporary interlude.

(b) The direct effects of the 1961 eruption on the vegetation

By J. H. Dickson, *The Botany School, Cambridge*

(1) *The nature of the direct effects*

The direct effects of the eruption on the vegetation were mediated by four different agencies:

(i) *Landslides and rockfalls*

These occurred on the Main Cliffs behind the volcano and in Hottentot Gulch, as a result of the earth tremors associated with the eruption. The largest rockfall was on the Main Cliffs immediately behind the Settlement. It is likely that the severe injury of the vegetation on these steep slopes, due to fumes emitted by the volcano, will reduce the efficiency of soil binding and facilitate further landslides.

(ii) *Fires*

Small, widely spaced, patches of *Phylica* bush on the slopes behind the volcano were set on fire by pyroclastics. The latter were found as high as 1000 ft. on the Main Cliffs.

Small patches of *Phormium tenax* in the Settlement were also set alight by pyroclastics, and in one area by contact with the lava field.

(iii) *Lava and ash*

About twenty acres of grassland and littoral vegetation were covered by lava, which obliterated Julia Point, a locality rich in marine algae. Ash covered about ten acres of the lower slopes of the Main Cliffs immediately behind the volcano, lying unevenly and nowhere exceeding 30 cm in depth. This relatively small amount of ash cover is unusual and differentiates the Tristan eruption from most of those studied elsewhere.

(iv) *Toxic fumes*

These caused far the most extensive of the direct effects of the eruption on the vegetation, and their predominance renders it of especial interest since well-attested examples of fume damage have rarely been studied.

(2) *The area of fume damage and nature of the fumes*

The area of fume damaged vegetation was determined by the interplay of two sets of factors. One group of these includes the nature and volume of the toxic gases released; the second group of factors includes topography and prevailing wind in relation to the position of the new volcano. The result was the confinement of fume damage to a strip of land about eight or nine square miles in area and seven miles in length, which is markedly asymmetric about the volcano. To the west (upwind) damage extends for little more than a mile, while downwind to the east it reaches to Sandy Point, a distance of six miles. The fume damage is confined to the lowlands, Main Cliffs and lower levels of the Base.

It is known that volcanic gases are often released in great volumes, and that highly toxic compounds such as H_2S, SO_2, HCl and HF may occur in quantity. No samples from the Tristan volcano were analyzed, but during the stay of the Expedition sulphur dioxide and hydrogen sulphide were recognized by their distinctive odours. Analysis of fumarolic minerals around the new volcano (this report pp. 555 to 558) has established the presence of sulphates, fluorides, chlorides, carbonates and borates so that it is likely that the major component of the fumes (after water) was SO_2, with smaller amounts of H_2S, H_2SO_4, HF, HCl and CO_2. The liberation of gases occurred principally between October 1961 and January 1962.

(3) *Nature of the fume damage*

It is well known that many of the gases present in volcanic emanations are toxic to plants. Hydrogen fluoride and sulphur dioxide are especially harmful, even at low concentrations and for brief periods, while hydrogen sulphide, hydrochloric acid and carbon dioxide are deleterious at higher concentrations and after longer periods. On Tristan the injured plants show symptoms comparable with experimentally induced sulphur dioxide damage. While drought is capable of inducing similar injury, the localization of the damage on Tristan to the strip close to and mainly downwind from the new volcano is sufficient evidence that volcanic rather than meterological factors are responsible.

Phylica arborea Thouars, the 'island tree' which dominates native vegetation at low levels around Tristan, was severely damaged by the fumes. In the area of maximum fume damage all the foliage on the *Phylica* bushes was dead, the leaves being turned a uniform brown and persisting on the stems. With increasing distance from the volcano more and more bushes showed only partial injury: in these cases it was characteristic that whole branches on a plant were completely browned while others on the same plant were free from observable injury. Damaged plants ranged from those with only one injured branch to those with only one living one. The gradation in damage was assessed in detail by counts in a series of quadrat areas at varying distances from the new cone. The results demonstrate clearly the asymmetry of the fume damaged area. West of the volcano, *Phylica* with dead foliage was not found more than $1\frac{1}{4}$ miles away; to the east at a comparable distance all bushes were completely damaged. Farther east, at $2\frac{1}{4}$ miles 34 out of 50 trees were more than 75% injured, and at $3\frac{1}{4}$ miles 20 out of 35 bushes had more than 50% of damaged branches. Some damage was found at Sandy Point, more than 6 miles east of the new cone.

Blechnum palmiforme Christensen, a dwarf tree fern, also showed severe damage in the area nearest the volcano. Here, the upper parts of the rachides and all but a few of the basal pinnae of the trophophylls were brown and dead. Farther away, less severely injured plants showed damage scattered around the margins of the pinnae on the trophophylls and sporophylls showed damage confined to the distal ends of the pinnae. By February 1962, almost all the damaged plants were producing new fronds. However, in the area of maximal damage, on the upper parts of the Main Cliffs behind the volcano, young and old fronds alike were badly damaged and in a few cases even the youngest unexpanded fronds were withered.

In the Settlement area, plants of the culivated New Zealand Flax, *Phormium tenax* J. R. & G. Forst., were without exception badly damaged by the fumes. The damage was largely confined to a more or less broad zone along the margins and at the tips of the leaves, the injured areas appearing bleached. Inflorescences which had been growing at the time of damage were withered and drooping.

These three species showed the most spectacular fume damage, but within the area of maximum damage all species of vascular plants were affected. *Empetrum rubrum* and *Blechnum penna-marina* showed rather clear-cut damage over a fairly wide area; in contrast the grass *Cynodon dactylon* which abounds on the Settlement plain showed damage only in close proximity to the new volcano. Bryophytes and lichens did not appear to be growing, and in some cases showed signs of damage, in the most affected areas.

(4) *Selective effect of the fumes*

Selective effects of volcanic gases on plants have been described from many parts of the world and were conspicuous on Tristan. Among indigenous plants, *Phylica arborea* and *Blechnum palmiforme* were most clearly affected, and were the only two plants appearing damaged on the Base and at the periphery of the affected area. In the Settlement area there was a striking variation in the effects of the fumes on the wide range of imported plants which grow there. The marked damage to *Phormium tenax* was paralleled by severe damage to *Acacia* sp., *Cupressus macrocarpa*, *Eucalyptus cornuta*, *Leptospermum laevigatum*, *Leucadendron argenteum*, *Persea americana*, *Pinus* sp., *Quercus cerris*, *Ulex europaeus*, and *Myoporum insularum*. Other species, including *Ficus carica*, *Hibiscus* sp., *Malus sylvestris*, *Metrosideros collina*, *M. excelsa*, and *Salix* sp., showed only very slight damage. On the other hand, the herbaceous plants growing in the Settlement apparently escaped injury, making an interesting comparison with the indigenous vegetation where again damage was concentrated in the shrub layer.

(5) *Recovery of the damaged plants*

In general, the fume-damaged *Phylica* bushes showed no signs of recovery during February and March 1962. However, two completely browned bushes growing high on the east-facing slope of Hottentot Gulch were found to have numerous new shoots sprouting from the base of the stem. Elsewhere, outside the area of maximal fume damage, many bushes were found to have tissue which appeared alive near the base of the stems, and these may put out new shoots in a similar manner. Within the area of maximal fume damage, however, almost all the bushes appeared completely dead and observations by H. G. Stableford in September 1962 confirmed that substantial recovery of the bushes in this area had not occurred. In areas burned by pyroclastics in the central zone small seedlings of *Phylica* were noted in February 1962.

In contrast to the widespread death of *Phylica*, few specimens of *Blechnum palmiforme* had failed to put out new fronds by February 1962. In the area of maximal damage *B. pennamarina* and *Hydrocotyle leucocephala* were producing new leaves at the same period, but other indigenous species in that zone showed no signs of recovery. In September 1962, however, *Carex thouarsianus* had begun to grow once more. It seems probable that outside the area of maximal damage vegetation recovery will be rapid, but that within that area *Phylica* re-growth will largely occur from seed, and some other species will also need to be replaced from seed or spore. It is possible that before adequate re-growth can occur in this central zone, the loss of soil stability (at present largely assured by the widespread roots of the *Phylica* bushes) will permit extensive erosion, thus further postponing vegetational replacement. The volcano, furthermore, may continue to emit small quantities of fumes, sufficient to check the vegetation nearest to the crater.

In the Settlement area, *Phormium tenax* showed no signs of recovery in February 1962. But by September 1962, Stableford found that vigorous new growth was being produced. Of the badly fume damaged trees and shrubs, *Acacia* sp., *Eucalyptus cornuta*, *Persea americana* and *Pinus* sp. were recovering by February 1962. It appears, from Stableford's observations, that the *Leucadendron* trees and the *Ulex* bush, on the other hand, are dead. Among herbaceous alien species the grass *Cynodon dactylon*, which appears to have hardly suffered even in the immediate vicinity of the new volcano, was actively colonizing a rubble of pyroclastics just west of the cone in February 1962 and was also growing in ash behind the volcano. This grass had in places succeeded in growing up through 15 cm of fine debris. Its survival even in the very severely damaged areas may be attributed to its rhizomes, and its rapid recovery accords with its behaviour in a volcanic area of Mexico.

Up to September 1962 the new lava field had not been colonized by plants, except in the western corner where a stream (Big Watrun) falls over the cliffs and splashes against the lava blocks. Here a growth of filamentous green algae has developed. This is a species of *Stigeoclonium*, perhaps *S. tenue* Kuetzing, and abundant diatoms occur among its filaments.

(c) The direct effects of the 1961 eruption on the fauna

By D. E. Baird, *Edward Grey Institute for Field Ornithology, Oxford*

(1) *Distribution of collecting stations in relation to zones of damage*

Invertebrates were collected by hand at thirty stations distributed among the main habitats on the island and grouped in four main zones:

(*a*) The severely affected zone very close to the new cone, where the ground surface was ash-covered and the vegetation severely damaged (5 stations).

(*b*) The mildly affected coastal zone in and around the Settlement itself, where the vegetation and fauna were probably initially comparable to those in the area close to the new volcano (2 stations), and in the fume damaged area on the Base, above the new cone (2 stations).

(*c*) The comparable but unaffected coastal zone between Stony Beach and Hackel Hill, and at Sandy Point (14 stations).

(*d*) The highland zone on the Base and Peak, where the vegetation was more or less natural and undamaged (4 stations).

In considering the results of this sampling, it must be remembered that the area of maximal volcanic damage lay on the Settlement Plain, which is the region most affected by man. The vegetation in this region is greatly modified and alien invertebrates are more abundant here than anywhere else on the island. Bird life is almost non-existent, while alien predators (cats, dogs and rats) and grazing mammals are most numerous. The new volcano thus exerted its effect on a highly modified biota.

(2) *The fauna in the most severely affected zone*

The new lava has covered about twenty acres of overgrazed grassland and the adjacent littoral strip. The consequent destruction of the local invertebrate fauna may have resulted in the loss from the island of the only known native Orthopteran, the endemic tridactylid *Tridactylus subantarcticus* Willemse, which has only been collected in this vicinity. Immediately to the east of the lava field, where ash cover was general, the soil and ground-surface fauna also appeared to have been killed out. The first living non-flying invertebrate was taken 200 m from the centre of the crater, under a stone buried beneath 2 cm of ash. It was the alien chilopod *Lithobius melanops* Newport. In the same area dead weevils and dead *Porcellio scaber* were found. Oligochaete tunnels occurred in the soil, which was quite moist, throughout this zone even to within a few metres of the lava field, but the first live worms were found 250 m from the new volcano, in moist soil overlaid with 15 cm of ash. Arachnids were not seen anywhere in the most severely affected zone. The only common invertebrates in the region were Diptera (*Lucilia sericata* being most abundant), which were seen resting on the warm stones of the lava itself and were apparently unaffected by the fumes still being emitted at the time of study. In all, of 10 invertebrate species collected in this zone, 6 were Diptera.

(3) *The fauna in the fume-damaged vegetation on the Base*

Two stations about $1\frac{1}{2}$ miles from the new volcano, on the edge of the Base and in rather severely damaged vegetation, proved to have abundant invertebrates. Although the two dominant plants, *Phylica arborea* and *Blechnum palmiforme*, had been badly affected by fumes, a complete fauna was found in the ground vegetation and on their trunks. Collembola and aphids (*Aulacorthum solani*) were especially abundant. The influence of fumes on the invertebrate fauna appeared to have been negligible, and this may in part have occurred because the two dominant plants, which seem to have been most checked by volcanic gases, generally support few phytophagous invertebrates. It is, however, impossible to assess the degree to which recolonization since the eruption had enriched the fauna.

In the same area, the breeding birds (especially the two albatrosses, *Diomedea chlororhynchos* and *Phoebetria fusca*, and the endemic 'starchy', *Nesocichla eremita*) appeared entirely unaffected by the eruption and were breeding among devastated vegetation.

(4) *The fauna in the slightly damaged area near the Settlement*

To the west of the volcano, where ash cover was negligible, the soil and litter fauna appeared unaffected even within 100 m of the base of the cone. Collembola and aphids occurred at this distance, and a station only $\frac{3}{4}$ mile from the centre of the main crater, which was worked intensively, provided an abundant fauna which did not differ significantly from that in undamaged areas of the coastal lowlands on the south and east of the island. In total, 30 species were obtained in the mildly affected area near the Settlement as opposed to 36 species at Stony Beach and 22 species in unaffected upland habitats.

(5) *Conclusions*

It is evident that, outside the zone immediately adjacent to the new volcano, the qualitative sampling methods employed revealed no evidence of any effect of the eruption on the invertebrate or vertebrate fauna. This was despite the fact that the vegetation showed severe damage over a far wider area. It is possible that more rigorous quantitative sampling would have revealed a reduction in the populations of phytophagous species in these wider areas of damaged vegetation, but there is no evidence on this point. Nor is it possible to assess the extent to which recolonization of the slightly damaged areas has occurred since the eruption passed its peak. However, it was thought in the field that all the evidence pointed to the volcano having a very slight influence only upon the alien and native fauna of the island. Consequently it may be suggested with some confidence that the recurrent eruptions of comparable magnitude which the island has experienced in recent millennia are unlikely to have had any great influence on the animal populations of the island.

APPENDIX II. AGE DETERMINATIONS MADE ON SAMPLES OF BASALT FROM THE TRISTAN DA CUNHA GROUP AND OTHER PARTS OF THE MID-ATLANTIC RIDGE

BY J. A. MILLER, *Department of Geodesy and Geophysics, Cambridge*

The technique of dating basic rocks and the factors which influence the apparent ages yielded by such determinations have been described by Miller & Mussett (1963). It has been shown that whole rock samples of basalt, provided that they are unaltered, can yield satisfactory ages when measured by the potassium-argon method.

In making measurements on geologically young samples with the equipment at present in use in this laboratory it has been found that errors arise mainly from inaccuracies in the measurement of argon isotope ratios.

TABLE 20. AGE DETERMINATIONS ON SAMPLES FROM TRISTAN

$\lambda_e = 0{\cdot}584 \times 10^{-10}$ yr^{-1}. $\lambda_\beta = 4{\cdot}72 \times 10^{-10}$ yr^{-1}.

	sample	reference	K_2O (%)	atmospheric contamination (%)	age + estimated error (m. yr.)
D 1	flow or large sill halfway between Big Point and Rookery Point. 10 ft. O.D.	295 Z/39	2·54	—	Recent
D 2		296 Z/46M	2·30	—	Recent
D 3		297 Z/38	2·73	12·2	3 ± 3
*E 1	flow halfway between Big Point and Rookery Point immediately beneath D 1, D 2, D 3	298 Z/45M	2·78	—	Recent
E 2		299 Z/56M	2·79	—	Recent
E 3		300 Z/43	2·81	94·8	$0{\cdot}5 \pm 1$
G 1	seaward edge of flow 100 yards extreme west of flow 10 ft. O.D.	301 Z/40	4·66	79·8	$0{\cdot}6 \pm 1$
G 4		302 Z/41	4·66	31·3	$0{\cdot}8 \pm 1$
I 1	flow forming 3rd waterfall above largest waterfall, Hottentot Gulch 1500 ft. O.D.	303 Z/42	2·65	—	Recent
I 2		304 Z/36	2·55	85·9	1 ± 1
I 3		305 Z/37	2·51	—	Recent
H 3	flow on seashore between Settlement and east of Herald Point 0 ft. O.D.	309 Z/51	3·14	—	Recent
H 2		310 Z/50	3·21	—	Recent
H 1		311 Z/52	3·18	—	Recent
J 1	flow approx. 100 yards west of pinnacle, Hottentot Gulch 900 ft. O.D.	312 Z/58M	2·38	—	Recent
J 2		313 Z/60M	2·51	—	Recent
906	basalt	M/5	1·64	—	Recent
BM	1927 1252 (22) E. 50, Settlement Plain	O/11	2·79	54·1	$3 \pm 1{\cdot}5$
BM	1927 1252 (2) E. 2, basalt from edge of lake	O/14	3·3	37·5	3 ± 1
BM 64747	basalt	O/8	2·9	77·5	9 ± 2

* *Note added in proof, 4 June* 1964. Two measurements have been made in the Cambridge laboratory by Mr R. L. Grasty on sample E 1 using the omegatron type mass spectrometer. This sample, which is from one of the lowest basalt flows exposed on Tristan, yielded ages of $0{\cdot}80 \pm 0{\cdot}10$ and $1{\cdot}10 \pm 0{\cdot}15$ million years. These results are in agreement with the earlier determinations.

In view of the normal direction of magnetization of the rock, it is concluded that the true age must lie very close to the figure of 0·95 million years obtained from the mean of the two values.

The basis of the potassium-argon method is the decay of potassium-40 to argon-40 by K-electron capture. Very young samples will therefore contain little argon-40. Argon-40 is also introduced into the apparatus from the atmosphere in the small amount of air occluded on to the surface of the rock sample. Atmospheric argon contains ^{40}A, ^{38}A and

^{36}A in known proportions, hence it is possible to correct the total argon for its atmospheric component by measuring the isotope ratios of the mixture. In measurements on rocks greater than a hundred million years old, the atmospheric argon content amounts to only a few per cent of the total argon volume. At ages of a few million years or less the atmospheric argon content (V_A) becomes large compared with that produced radiogenically from potassium within the sample (V_R). As the ratio V_A/V_R rises it becomes increasingly important to make an accurate correction for argon of atmospheric origin.

TABLE 21. AGE DETERMINATIONS ON SAMPLES FROM GOUGH, NIGHTINGALE AND INACCESSIBLE

$\lambda_e = 0{\cdot}584 \times 10^{-10}\ \text{yr}^{-1}$. $\lambda_\beta = 4{\cdot}72 \times 10^{-10}\ \text{yr}^{-1}$.

	sample	reference	K_2O (%)	atmospheric contamination (%)	age and estimated error (m. yr.)
82013	olivine basalt, the Glen, Gough Island	M/6	2·33	21·5	6 ± 2
G 159	trachyte plug at head of Deep Glen, Gough Island	O/9	5·5	78·2	3 ± 1
G 80	trachyte, near sea-level Waterfall Point, Gough Island	O/10	5·8	44·7	2 ± 1
BM 64775	basalt from dyke intruding rear of Blomby's Cove, Nightingale Island	O/12	4·8	95·5	2 ± 1
BM 64760	basalt from Inaccessible Island	O/13	1·9	43·2	$6 \pm 1{\cdot}5$

TABLE 22. AGE DETERMINATIONS ON ROCKS FROM MIDDLE ISLAND (NIGHTINGALE)

$\lambda_e = 0{\cdot}584 \times 10^{-10}\ \text{yr}^{-1}$. $\lambda_\beta = 4{\cdot}72 \times 10^{-10}\ \text{yr}^{-1}$.

	sample	reference	K_2O (%)	atmospheric contamination (%)	age and estimated error (m. yr.)
BM 1927	1252 41 basalt from Middle Island	O/5	3·73	97·8	12 ± 4
BM 1927	1252 41 basalt from Middle Island	O/7	3·73	96·6	18 ± 4

The majority of rocks from Tristan contained so little radiogenic argon that it was impossible to measure the age accurately. The term 'Recent' in table 20 is to indicate those samples in which the atmospheric argon content was very large (greater than 99 %) compared with radiogenic argon. All the samples of basalt from Tristan used in this work, except for the last four listed in table 20, were collected by the Royal Society Expedition to the island in 1962. The last three samples shown in table 20 were provided by the British Museum. Twenty samples were measured in all and show remarkably consistent results save that yielded by sample BM 64747. The exact locality of this rock is not known and in view of the similarity of the rest, it can be neglected.

Discussing the morphology of the various islands of the Tristan da Cunha Group, members of the Expedition note (p. 456 and 457) that Tristan itself is only eroded along the Main Cliffs and in the vicinity of the Peak; Inaccessible represents the relatively undissected eastern quadrant of a once nearly circular volcanic cone whilst the islands of the Nightingale Group are the remnants of a very deeply eroded volcanic pile. These observations are in complete agreement with the absolute age determinations: Tristan 1 million years, Inaccessible $6 \pm 1{\cdot}5$ million years and Middle Island (Nightingale) 18 ± 4 million years.

TABLE 23. AGE DETERMINATIONS ON TWO SAMPLES OF SUBMARINE BASALT

$\lambda_e = 0{\cdot}584 \times 10^{-10}\ \mathrm{yr}^{-1}$. $\lambda_\beta = 4{\cdot}72 \times 10^{-10}\ \mathrm{yr}^{-1}$.

	sample	reference	K_2O (%)	atmospheric contamination (%)	age and estimated error (m. yr.)
1954	152 station number 2493 depth 472 m, Discovery sea mount. Lat. 42° 03·9′ S, long. 0° 03·5′ E	O/15	1·5	90·6	26 ± 4
86939/4519-54	basalt from Mid-Atlantic Ridge. Long. 27° 43′ W, lat. 45° 44′ N	O/6	0·60	37·3	29 ± 4

TABLE 24. RELATIONSHIPS BETWEEN AREA, AGE AND ALTITUDE

island	age (m. yr.) (average of all measurements)	area (km^2)	altitude (ft.)
Tristan	1	86	6760
Gough	4	57	2967
Inaccessible	6	12	1800
Nightingale	15	4	1000
Discovery seamount	26	—	−1548

In the Tristan da Cunha Group, the degree of erosion, the area and the height of the three main islands are directly related to their maximum radiometric ages (see table 22). Clearly any universal correlation between age and height is unlikely, as not all oceanic islands are of the same height initially. If seamounts are the remains of foundered oceanic islands then it would be expected that their ages would be greater than those of the islands. The result of an age determination made on a basalt from a seamount situated at known depth is given in table 23 and is consistent with this view.

Table 24 shows the marked relationship between average age, area and altitude and should be compared with tables 14 and 15. It is of interest to note that the average age of 4 million years for Gough Island (table 21) seems also to be related to the height and area of this island.

Oceanic islands on the whole are isostatically unstable and tend to subside into the sea. The results presented here are in agreement with this hypothesis and suggest that the life span of a basaltic oceanic island would be about 20 million years. It would be expected that islands consisting of less dense rock such as phonolite would have a longer life. This matter is at present being investigated.

APPENDIX III. PALAEOMAGNETIC MEASUREMENTS ON LAVAS FROM TRISTAN AND INACCESSIBLE ISLAND

By K. M. Creer, *Department of Physics, University of Newcastle-upon-Tyne*

Procedure

From each of ten sites three orientated hand samples had been collected. From each hand sample about three cylindrical specimens of diameter and length equal to 1 in. were machined. Their remanent magnetizations were measured with a simple astatic magnetometer (Collinson, Creer, Irving & Runcorn 1957). The localities of the sites and the types of rock collected are listed in table 25.

Table 25

site	locality	rock type
A	lava flow outcropping in beach. Runaway Beach, Tristan	vesicular basalt
B	flow immediately above white tuff horizon. $\frac{1}{4}$ mile S.E. Crawford Point. 250 ft. O.D. Tristan	vesicular basalt
C	flow from Stony Hill parasitic volcano. Tristan	vesicular trachyandesite
D	flow halfway between Big Point and Rookery Point 10 ft. O.D. Tristan	coarsely porphyritic pyroxene-olivine trachybasalt
E	flow halfway between Big Point and Rookery Point immediately beneath D/1, 2, 3. Tristan	vesicular porphyritic basalt
F	behind the huts at the landing near the Waterfall. Inaccessible	vesicular basalt
G	seaward edge of flow 100 yd. from extreme west of 1961–62 lava field. Tristan	trachyandesite 1961–62 eruption
H	flow outcropping on the sea shore below the Settlement and east of Herald Point. 0 ft. O.D. Tristan	vesicular leucite-bearing trachybasalt
I	flow forming third waterfall above largest waterfall, Hottentot Gulch. 1500 ft. O.D. Tristan	fine-grained trachybasalt
J	flow approx. 100 yd. west of Pinnacle, Hottentot Gulch. 900 ft. O.D. Tristan	fine-grained fissile trachybasalt

The measurements

In table 26 are listed the mean direction and intensity of magnetization at each site with the usual statistics (Fisher 1953). The stability of the natural remanence was investigated by demagnetization in an alternating magnetic field and fields required to reduce the natural intensity by half are listed in the final column. The directions of magnetization of individual cylinders are plotted on a stereographic projection in figure 92. Figure 93 shows the ten-site mean directions.

TABLE 26

site	N	R	D	I	α	δ	M	H_a
A	11	10·9710	N 3°·9 W	−51°·1	2°·5	4°·4	11·9 ± 2·0	420
B	11	10·9464	N 7°·8 W	−40°·6	3°·4	5°·9	5·4 ± 0·6	200
C	12	11·6970	N 19°·7 E	−54°·8	7°·3	13°·4	19·3 ± 3·2	450
D	11	10·8844	N 0°·9 W	−52°·4	4°·9	8°·7	6·9 ± 1·8	170
E	12	11·8875	N 15°·2 W	−51°·1	4°·4	8°·2	5·9 ± 1·4	120
F	12	11·9762	N 160°·9 E	+73°·3	2°·0	3°·8	6·5 ± 0·8	300
G	20	19·5436	N 16°·6 W	−49°·6	5°·1	12°·6	5·9 ± 2·4	120
H	10	9·7358	N 15°·0 E	−56°·0	8°·4	13°·9	10·2 ± 1·3	80
I	14	13·9482	N 13°·3 E	−56°·1	2°·5	5°·1	6·8 ± 1·0	200
J	12	11·3230	N 1°·1 E	−33°·8	11°·1	20°·1	4·0 ± 1·0	100
present field	—	—	N 27° W	−54°	—	—	—	—
theoretical dipole field	—	—	N 0° E	−57°	—	—	—	—
mean of sites	9*	8·8458	N 0°·0 E	−50°·2	7°·2	11°·2	—	—

N Number of cylinders (unit vectors) for a site.
R Length of resultant vector for a site.
D Mean declination (degrees) at a site.
I Mean inclination (degrees) at a site.
α Radius of confidence at $P = 0{\cdot}05$ (degrees) (equivalent to about twice the standard error of a normal distribution).
δ Angular dispersion ($\cos^{-1} = R/N$) (equivalent to the standard deviation of a normal distribution).
M Mean intensity (milligauss). Standard error also given.
H_a Peak a.c. field required to reduce remanence by half (oersted).
* Each normal site mean direction treated as unit vector.

TABLE 27. MEAN POLE POSITION

(Computed by allotting each site-mean pole unit weight)

N	R	longitude	latitude	α	δ
10	11·3230	24°E	87°N	9·3	15·3

Comments on the results

(1) The nine sites on Tristan are normally magnetized. That (site J) on Inaccessible is reversely magnetized. Palaeomagnetic measurements on Quaternary igneous rocks indicate that the most recent reversal of the earth's field occurred at the first to second glacial stage of the Pleistocene, i.e. 200000 to 1000000 years ago (Doell & Cox 1961). Since all the flows are dated as Recent it is unlikely that the flow at site F cooled down during an earlier period of reversal of the geomagnetic field than this. Hence the magnetic measurements indicate that the flow at site F dates from this most recent period of reversal and that at the other sites the flows are younger than this.

(2) The mean of the nine normal site-mean directions is N 0° E, −50·2°. Its circle of confidence, within which it is 95% probable that the true mean lies, ($P = 0{\cdot}05$) has a radius of 7·2° and so includes the theoretical axial dipole field direction but excludes the present field direction. Hence the mean direction of magnetization of all the flows is not significantly different from that of the axial dipole field. It is, however, significantly different from the present direction of the geomagnetic field. This result is typical for recent lavas from all over the world.

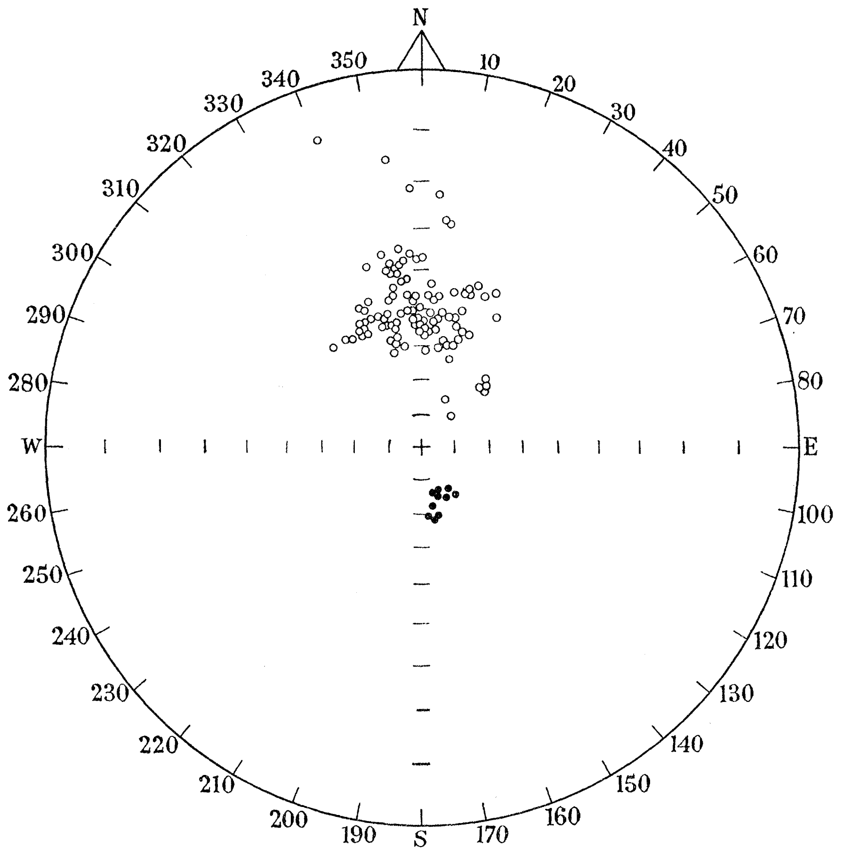

FIGURE 92. Directions of magnetization of cylinders cut from land samples.

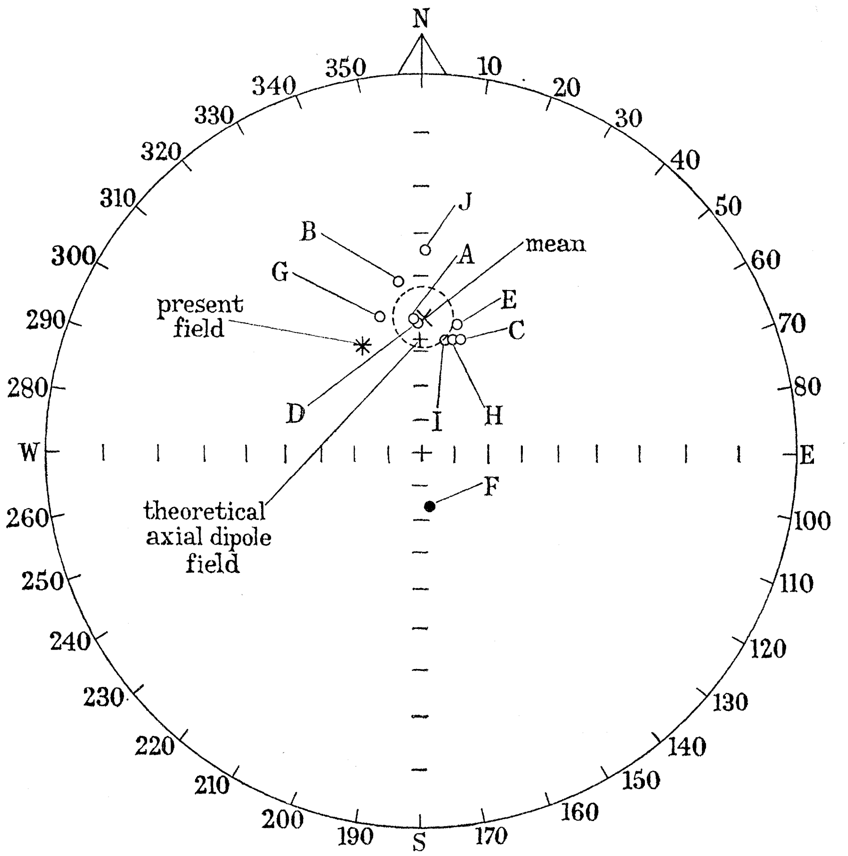

FIGURE 93. Site mean directions of magnetization of recent lavas from Tristan.

(3) Samples collected from site G are from flows erupted in 1961–62. The mean direction of magnetization for this site (N 16·6° W, −49·6°), and the radius of the cone of confidence at $P = 0{\cdot}05$ (of 5·1°) is less than the angle of 9° made with the present field (N 27° W, −54°) as read off from isogonic and isoclinic charts for 1960 published by the Hydrographic Department of the Admiralty. This is probably because of a local anomaly in the geomagnetic field over the islands due to the whole sequence of lava flows. Thus the field in which the lavas cooled is unlikely to be identical with that shown on the Admiralty chart and the slight disagreement of the mean direction of magnetization at site G with the present field is not unexpected.

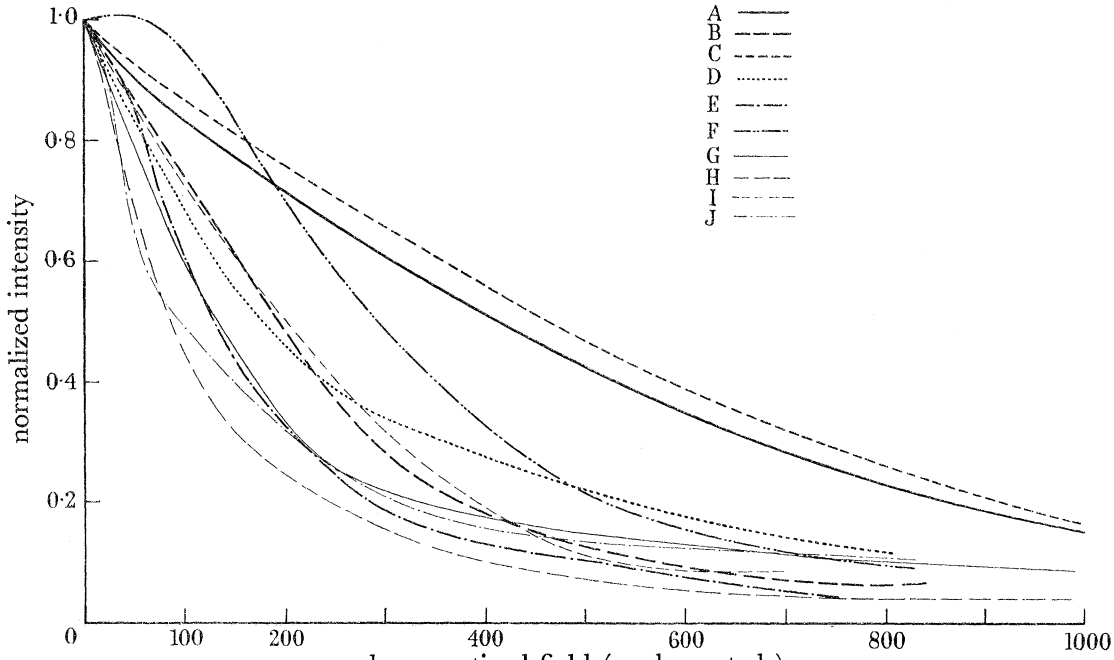

FIGURE 94. Stability of natural remanence of recent lavas from Tristan.

(4) The stability of the natural remanence was tested by demagnetization of some of the samples in alternating magnetic fields (Creer 1959). None of the site mean directions of magnetization changed significantly during these experiments. Demagnetization curves are shown for one sample from each site in figure 94. The angular difference between magnetization directions before and after treatment in 400 oersteds is less than 4° for most specimens, but about 10° for specimens from sites H and J. It is unlikely that the site-mean directions will be changed appreciably when all the specimens have been treated, since the changes in individual specimens appear to be random. In figure 95 an interesting relationship between the angular dispersion of directions of magnetization of specimens within a given site and the alternating field H_a required to demagnetize them to half their initial intensity is illustrated. This shows that the dispersion of magnetization between specimens within a site due to slight remagnetization either in the field or in the laboratory increases very rapidly as H_a decreases below 100 oersteds, peak value. The reason why the point for site C does not lie near the curve is that the rock compass used (Bidgood & Harland 1959) for orientating the samples developed a fault at this site and hence the large dispersion for this site is due to this cause.

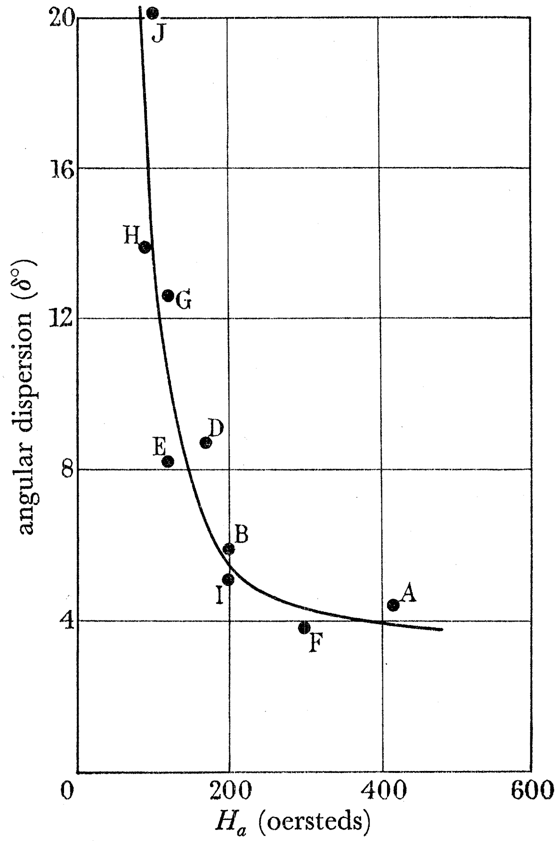

FIGURE 95

Conclusion

The mean direction of natural remanence of lava flows from nine sites on Tristan is not significantly different from the theoretical axial dipole field.

The flow from Inaccessible is reversely magnetized and hence probably dates from the early Pleistocene. The nine flows on Tristan are probably all younger than this. The natural remanence of the flows has been shown to be stable by demagnetization experiments in alternating magnetic fields.

Thermal experiments and more alternating field demagnetization work are being carried out on these rocks.

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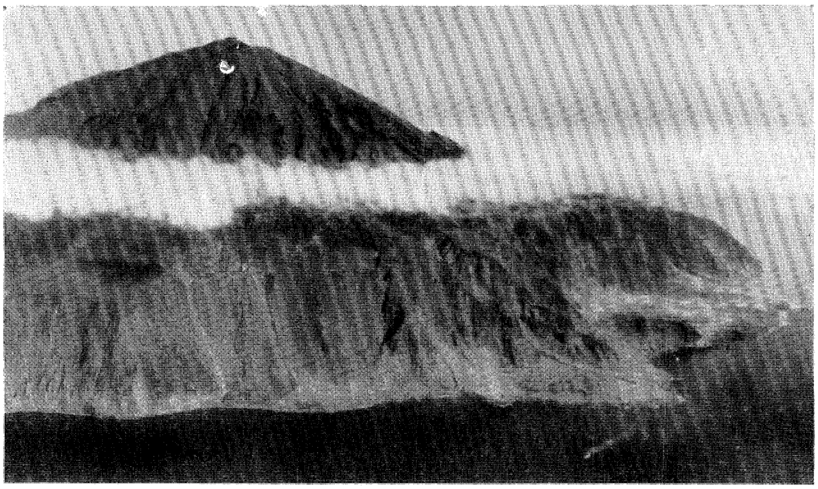


FIGURE 21. The north side of Tristan: taken from H.M.S. *Protector*'s helicopter in 1960 before the eruption. The typical volcanic form of the island is well illustrated, as is the Settlement coastal plain.

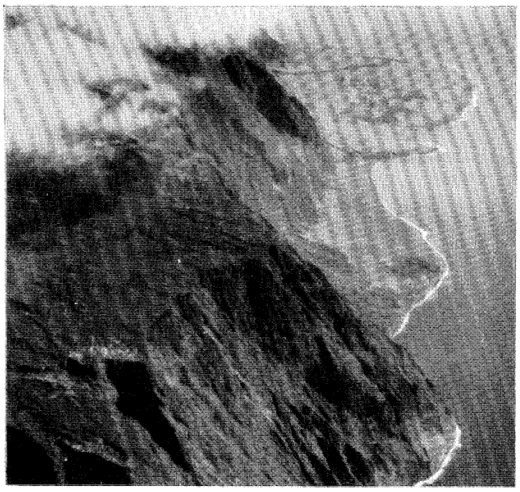


FIGURE 22. A view westwards along the northern coast of Tristan illustrating the steepness of the Main Cliffs and their sharp contact with the Base.

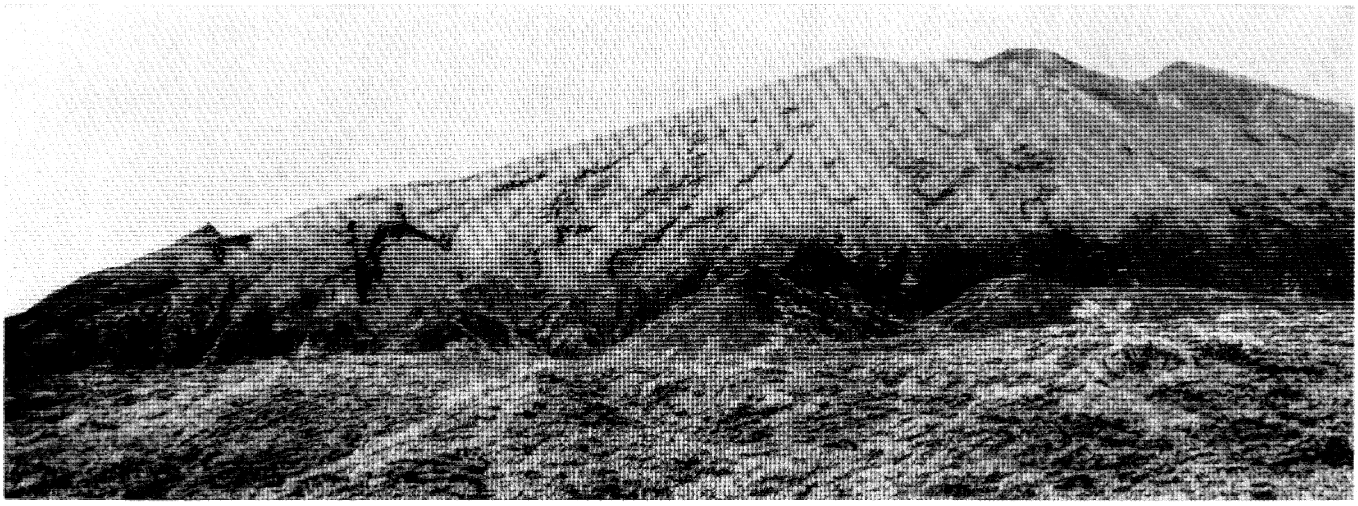


FIGURE 23. The Peak from the west (Burntwood): this view emphasizes the difference in slope of the Peak and the Base.

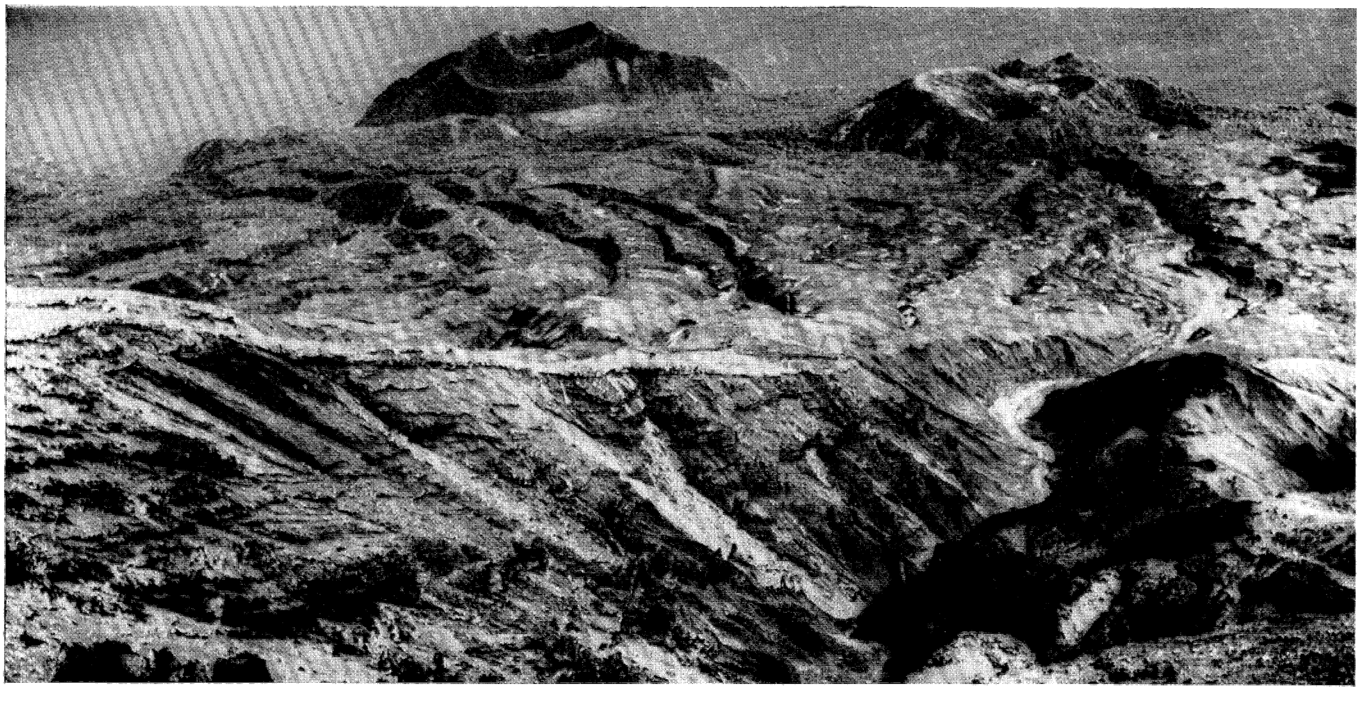


FIGURE 24. The south side of Tristan from Queen Mary's Peak: the gradual decrease in gradient away from the summit is illustrated. The parasitic cinder cones of Stony Beach Hills and Cave Gulch Hill are prominent at the edge of the Base.

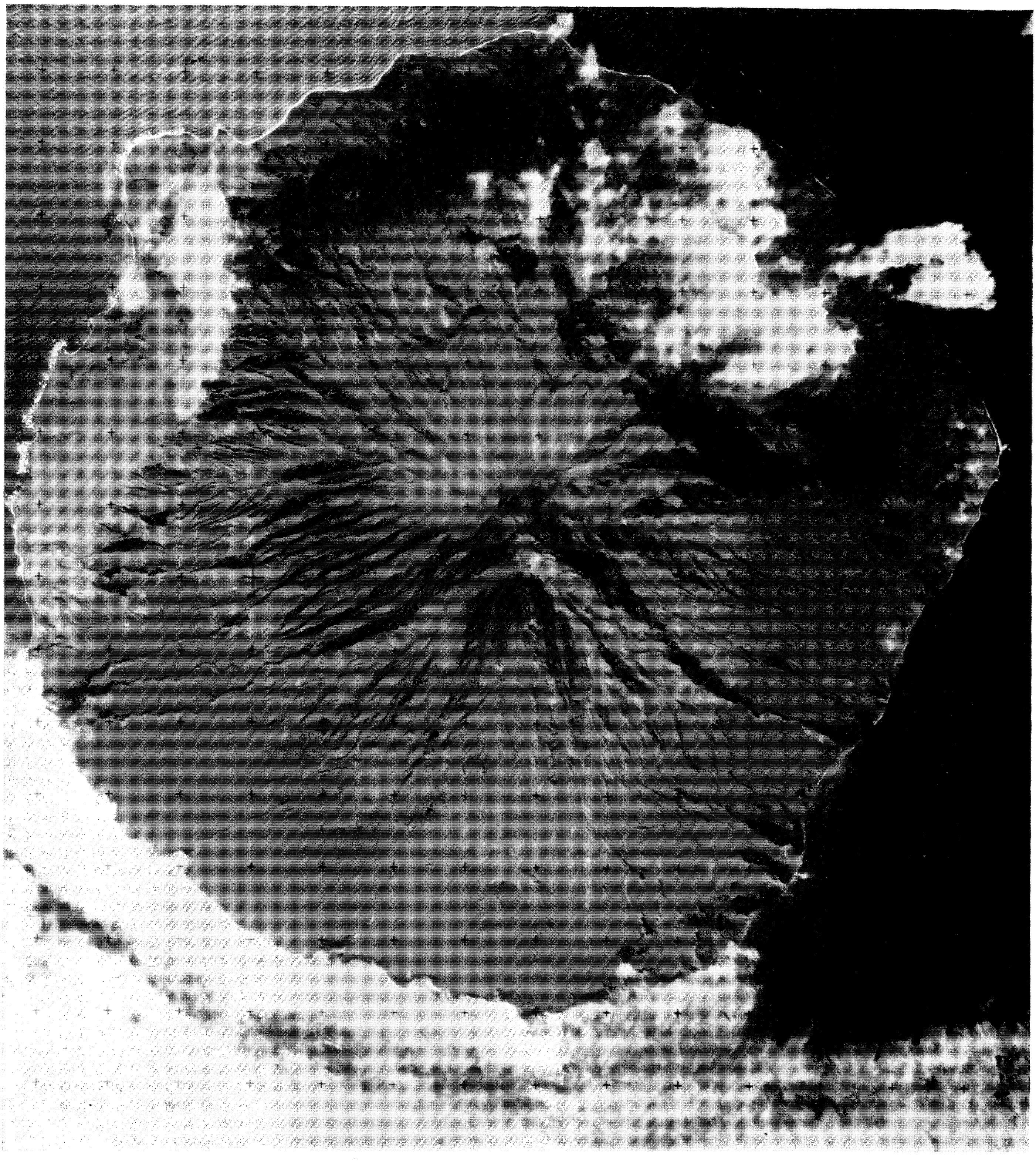


FIGURE 25

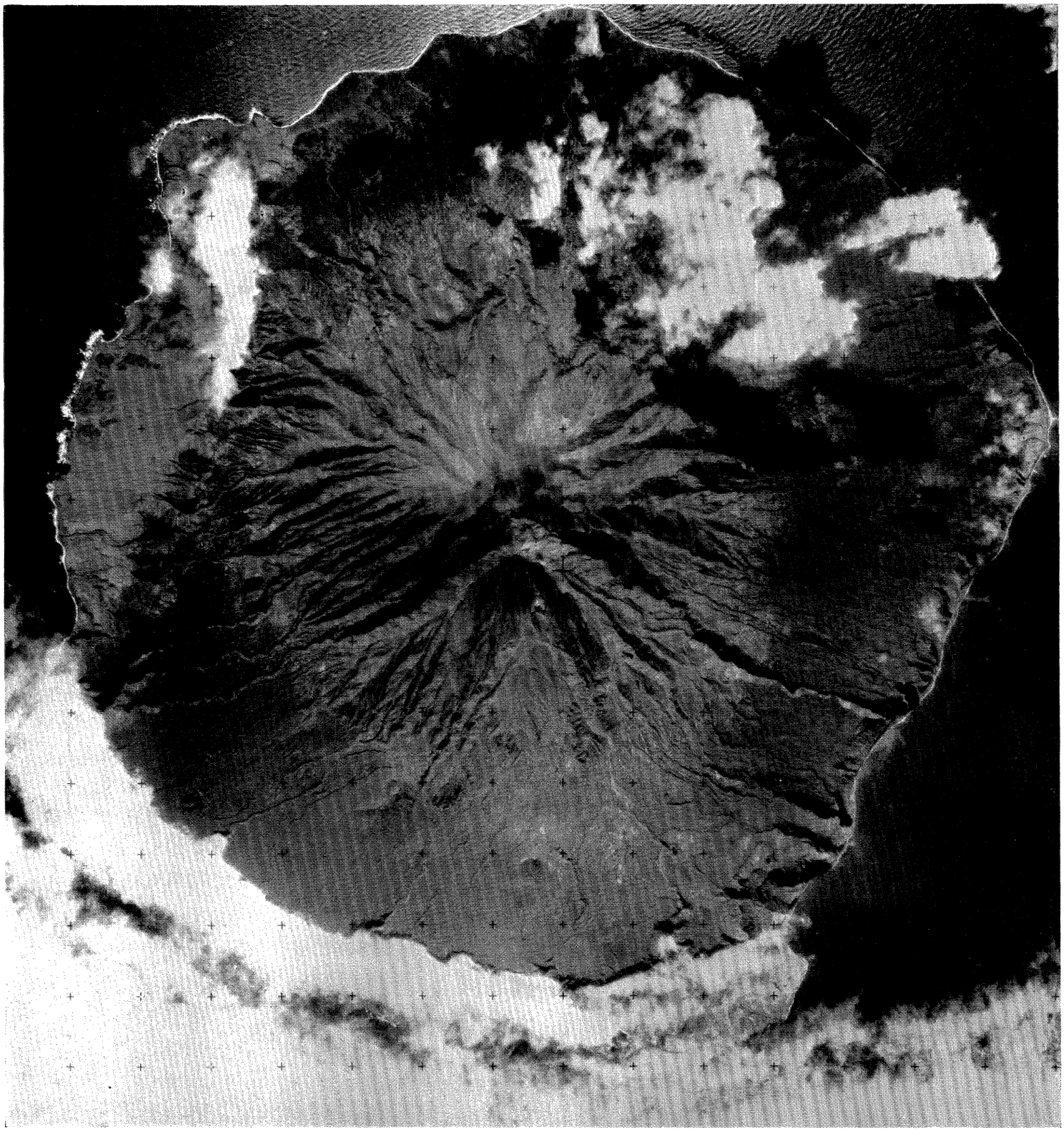


FIGURE 26

FIGURES 25 AND 26. Stereopair of aerial photographs of Tristan taken by the Royal Air Force on 3 April 1961 from 42000 ft. To be examined with a mirror stereoscope.

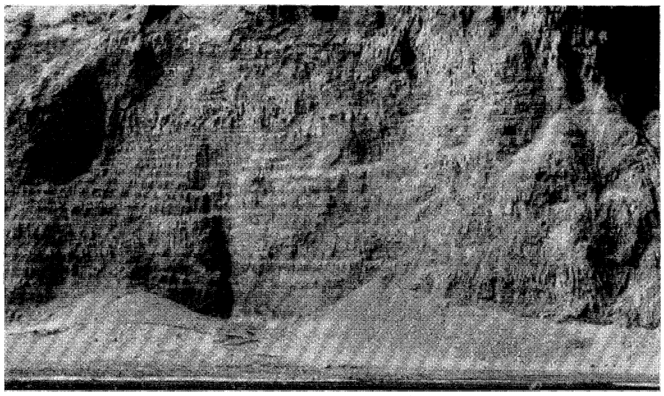


FIGURE 27. Main Cliffs near Pigbite; trachybasalt lavas of the main sequence with interbedded fragmental horizons which are the rubbly tops and bottoms of the adjacent flows.

FIGURE 28. East end of Sandy Point Gulch; Sanc Point parasitic centre, a parasitic complex within tl main sequence showing thick flow-banded trach basalt lavas flowing over red basaltic agglomerat

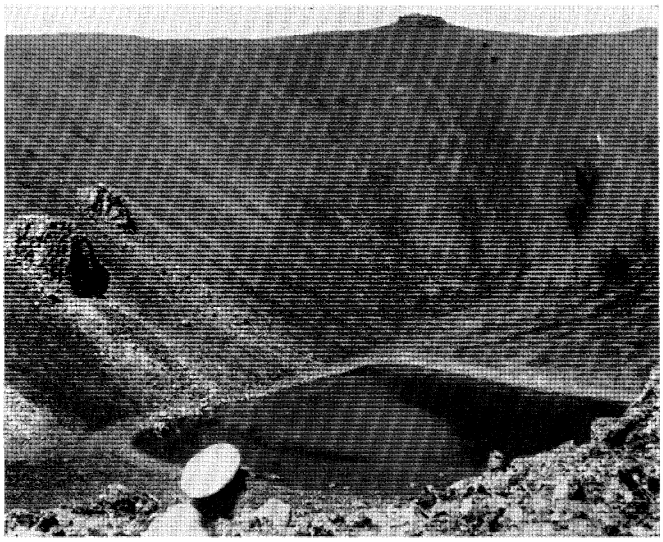


FIGURE 29. The summit crater lake.

FIGURE 30. Rock stripes: solifluxion phenomena on the rim of the summit crater.

FIGURE 31. Trachybasalt dyke exposed in Main Cliffs, Big Point.

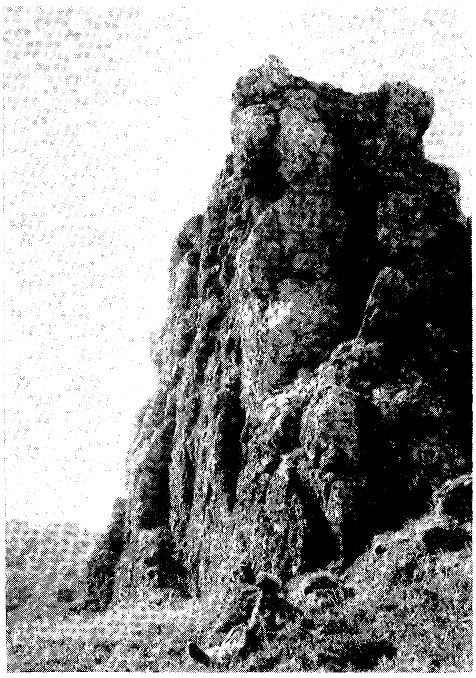


FIGURE 32. Wall dyke near the summit; upper reaches of Deep Gulch. 5750 ft. O.D.

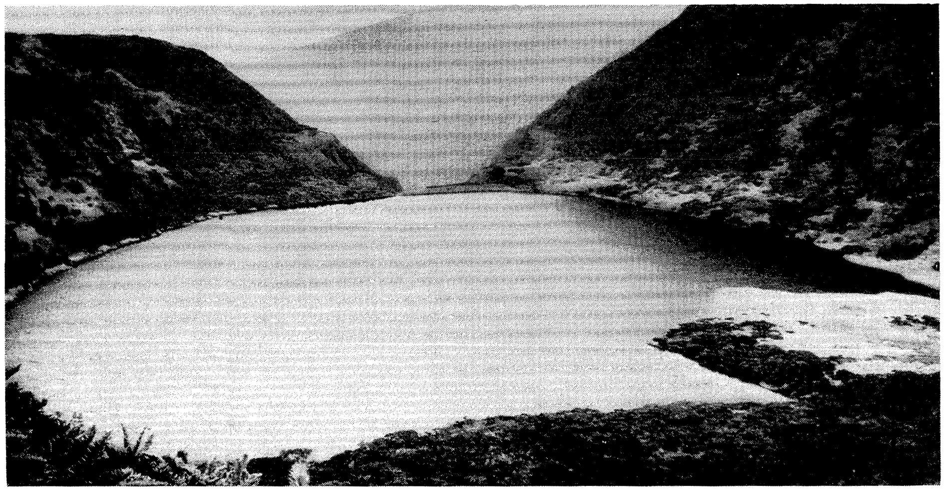


Figure 33. Top Pond from its southern rim: showing the V-shaped outlet on the north side. This outlet is not an erosional feature but is due to crater overlap.

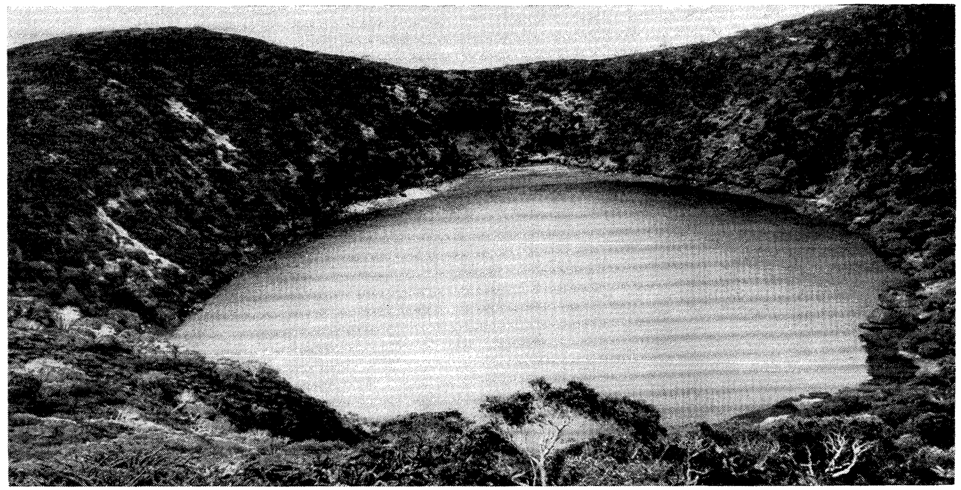


Figure 34. Bottom Pond from the southern rim: showing pebble beach and exposure of tuff and agglomerate in the northern crater wall.

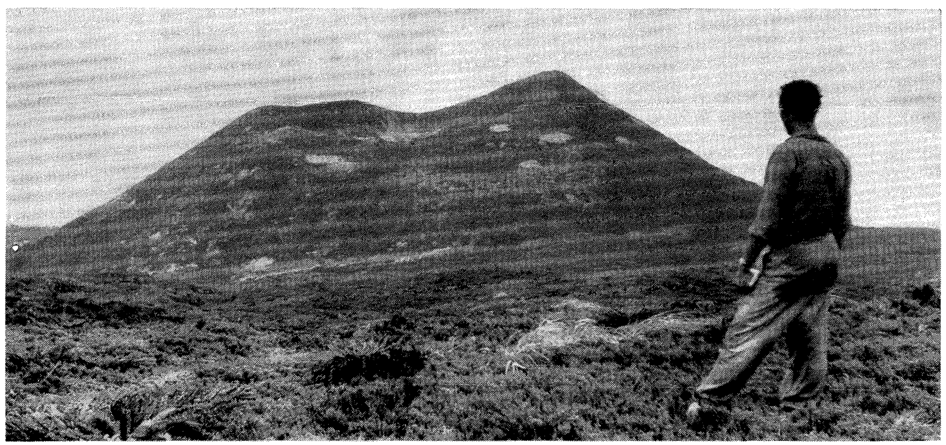


Figure 35. Big Green Hill from the south: a typical cinder cone now almost completely vegetated. A carbonaceous layer underlies the cinder cone and is exposed where Pigbite Gulch dissects the western flank. Radiocarbon dating indicates an age of 10770 ± 156 B.P. for the carbonaceous layer indicating an age of about 10 000 years for the cinder cone.

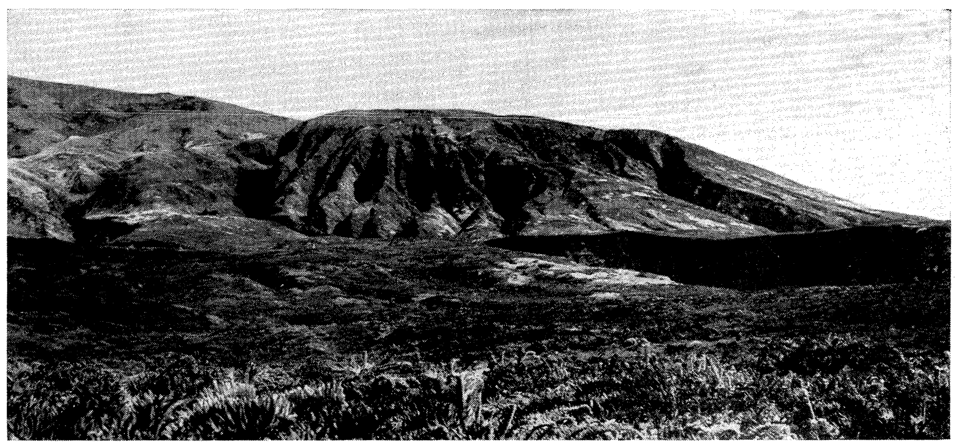


Figure 36. Nellie's Hump from the north-east: an old parasitic scoria mound whose form has been considerably modified by erosion. Typical badland gullying on the north-east flank reveals volcanic agglomerate.

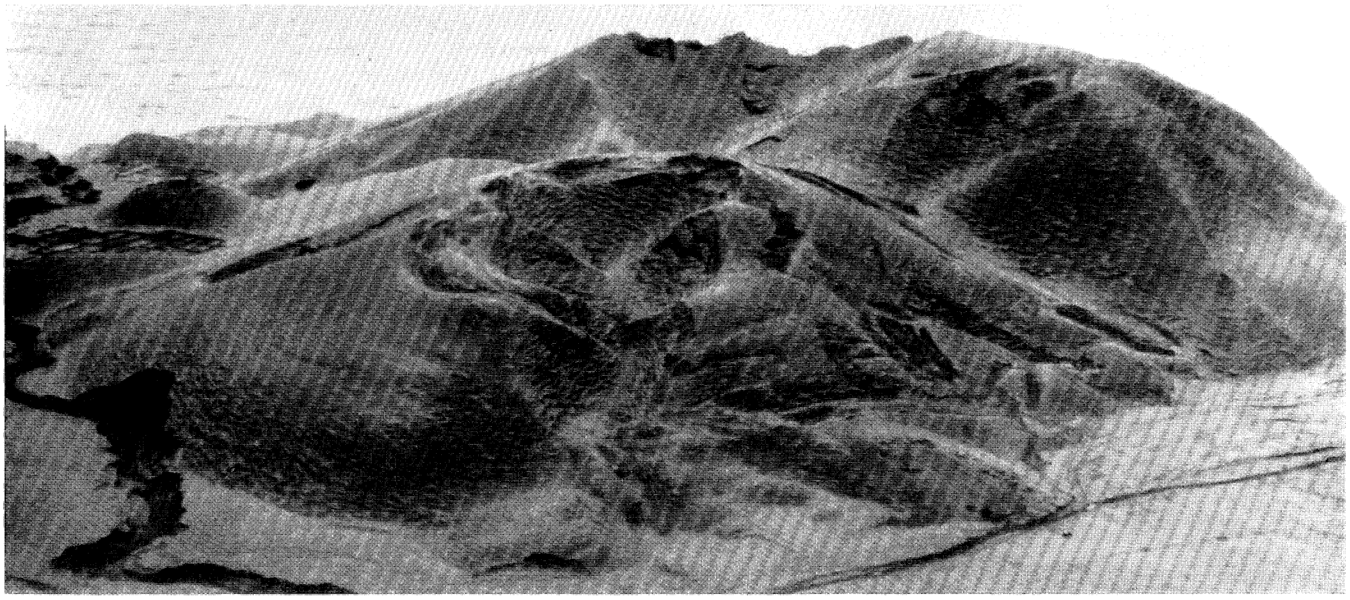


FIGURE 37. The Hillpiece parasitic complex from the east showing Burnthill in the foreground. Photograph taken from half-way up the Main Cliffs.

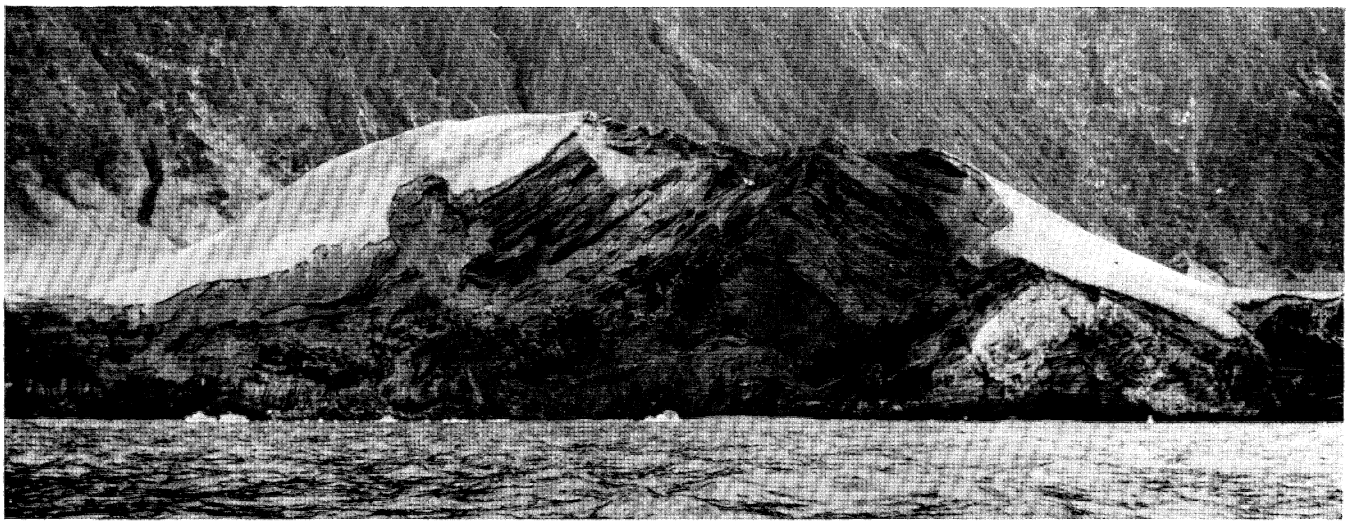


FIGURE 38. Hillpiece from the sea.

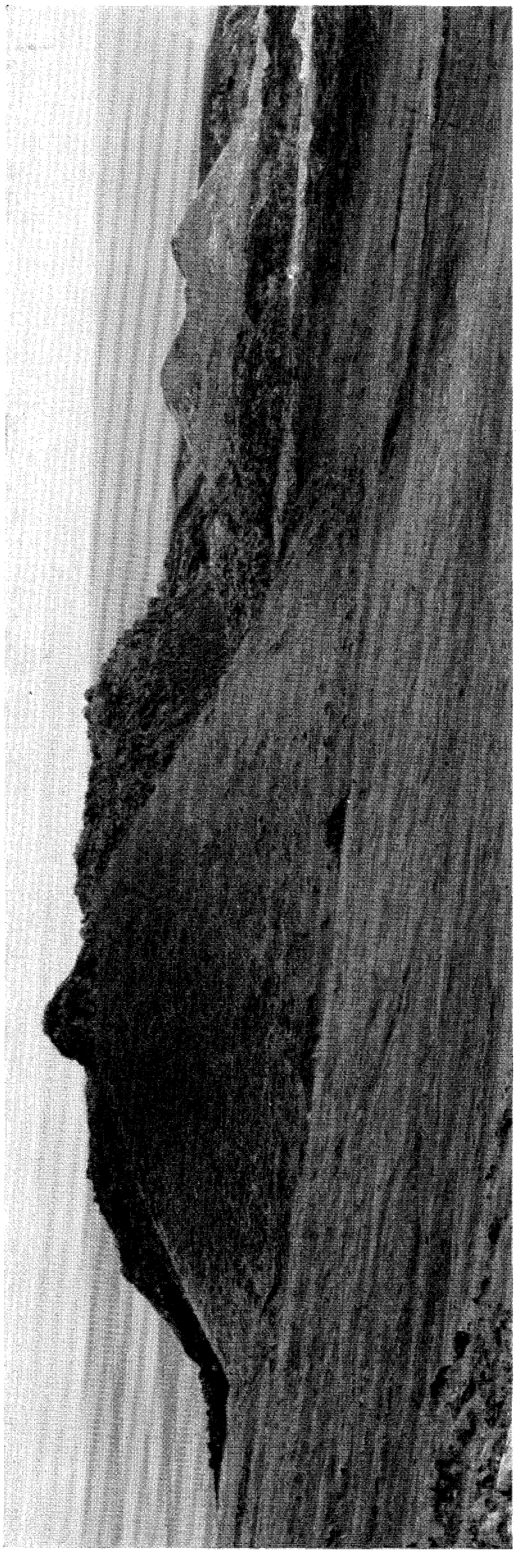


FIGURE 39. The Stony Hill Group from the north-west: Hill-with-a-hole-in is in the foreground partly obscuring Stony Hill. Kipuka Hill is to the right of Stony Hill.

FIGURE 40. Stony Hill from the summit of the Hill-with-a-hole-in.

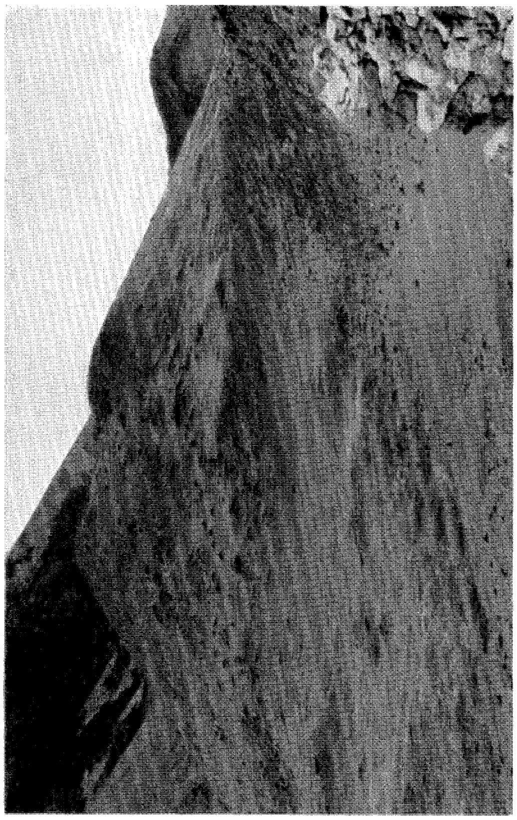


FIGURE 41. Hill-with-a-hole-in from the south-west showing the narrow lava flow that issued from the base of the cinder cone.

FIGURE 42. The Settlement Plain south of Hillpiece from the Base at Burntwood.

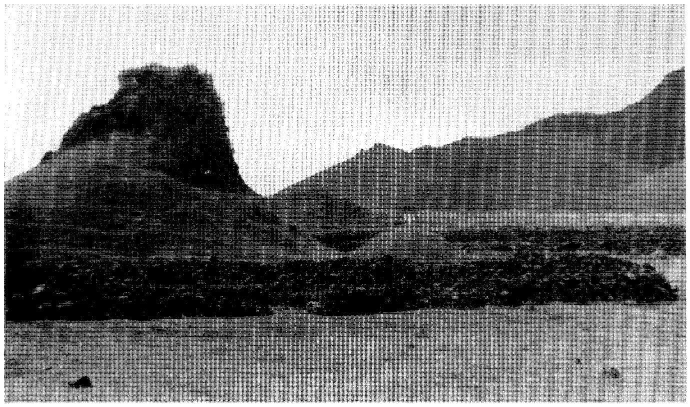


FIGURE 43. Hornitos on the Settlement Plain south of Hillpiece in the vicinity of the potato patches.

FIGURE 44. Entrail lavas on the foreshore north of the Settlement and immediately west of the 1961 lava.

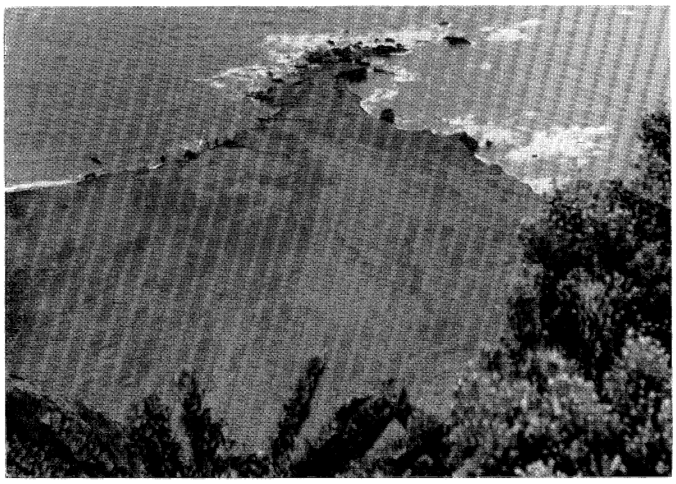


FIGURE 45. Seal Bay Plateau from the top of the Main Cliffs.

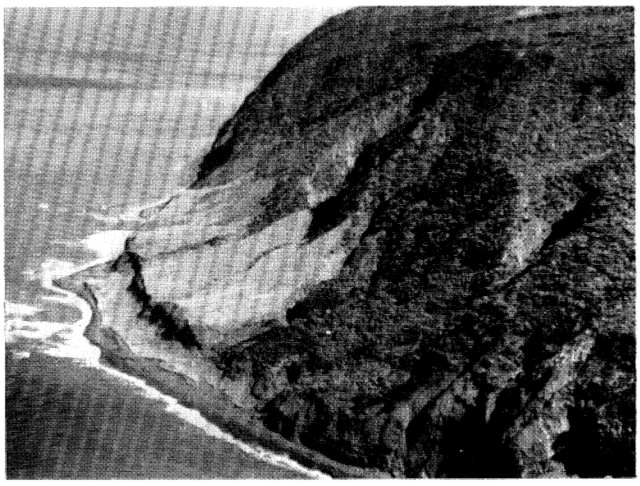


FIGURE 46. Sandy Point: the eastern extremity of Tristan.

FIGURE 47. The Nightingale Group from the north: note the absence of any volcanic landscape form.

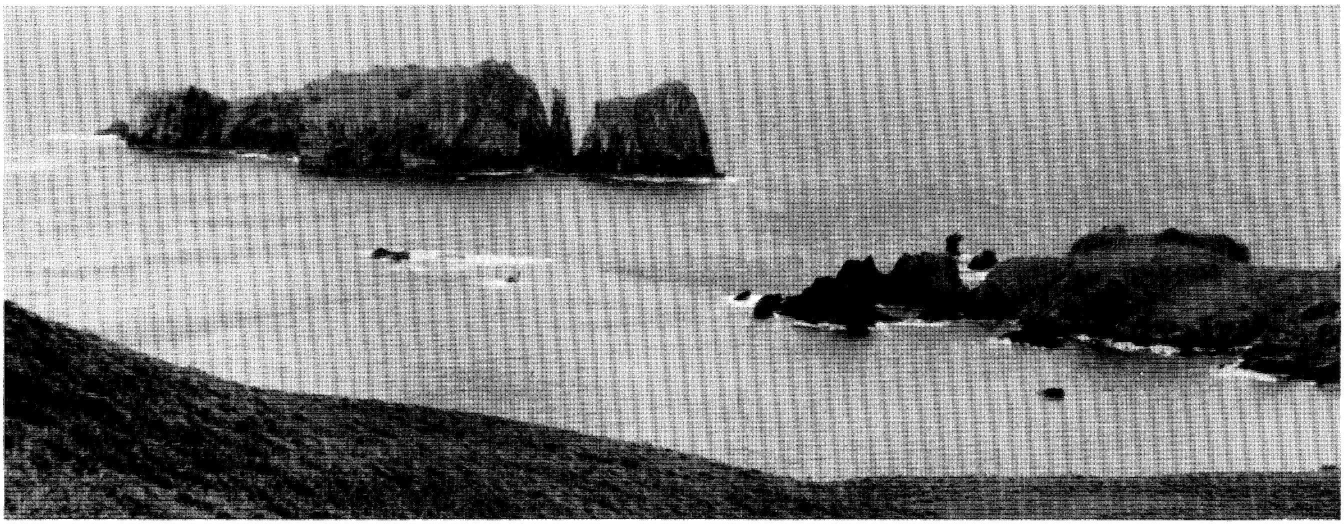


FIGURE 48. Middle and Stoltenhoff Islands from the vicinity of the 'Molly' Ponds on Nightingale.

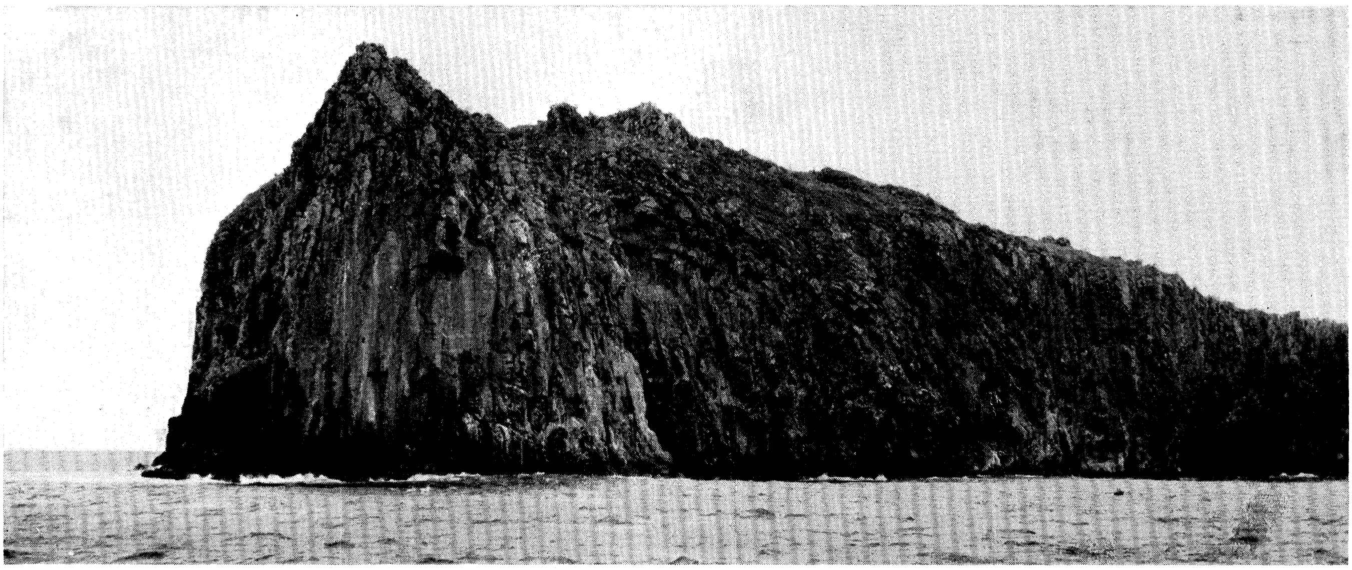


FIGURE 49. The south-western end of Stoltenhoff Island: Stoltenhoff is a monolithic mass of biotite trachyte, columnar jointed in places.

FIGURE 50. High Ridge: the ridge of high ground forming the eastern part of Nightingale Island seems to be a monolithic mass of trachyte.

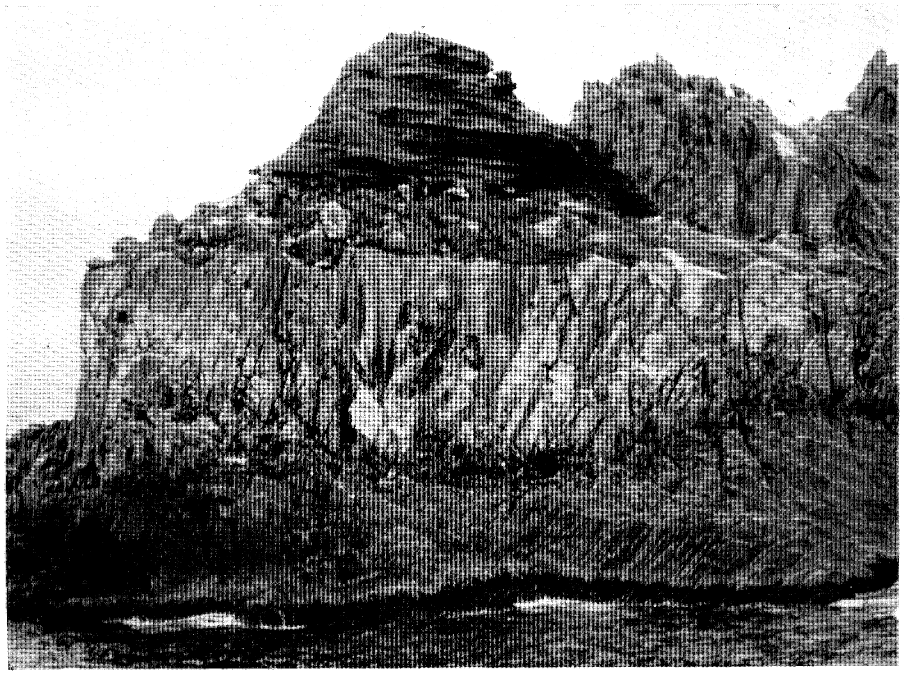


FIGURE 51. The hardie off Sea hen Rocks: these rocks are formed of trachyte overlain in part by buff coloured tuff. Between the trachyte and the tuff is a carbonaceous layer (covered by grass in photograph) dated as 39160^{+6090}_{-3410} years B.P. by radiocarbon methods.

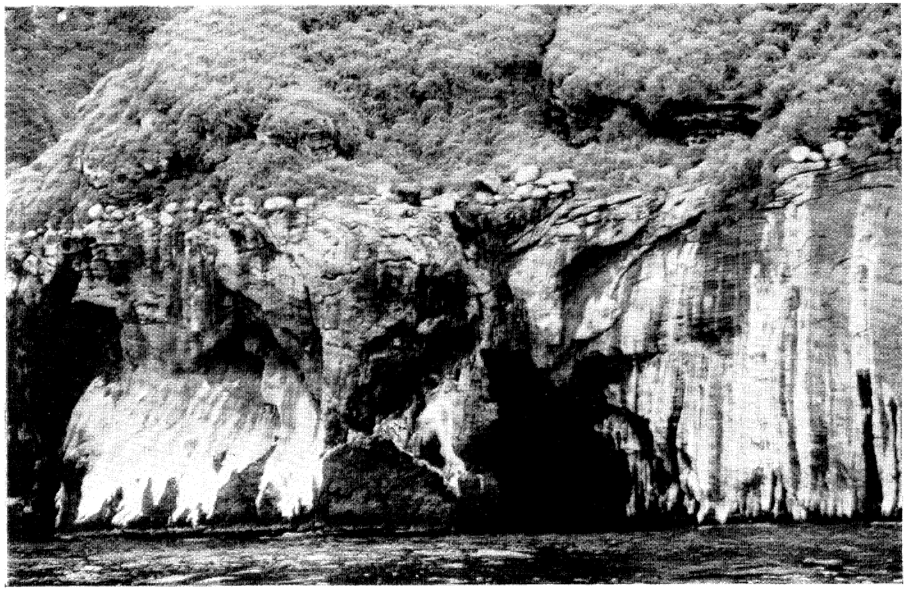


FIGURE 52. The sea cliffs on the eastern side of Petrel Bay. The boulder bed

FIGURE 53. The 'Molly' Ponds: North Pond from the east.

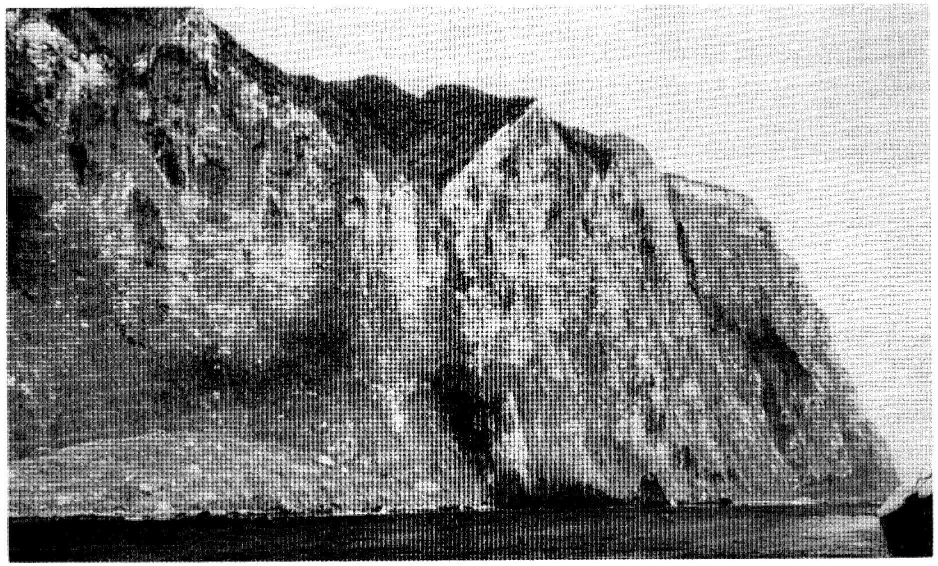


FIGURE 54. South-east coast: vertical white lines are dykes. Note the gentle eastern inclination of the lavas of the main sequence.

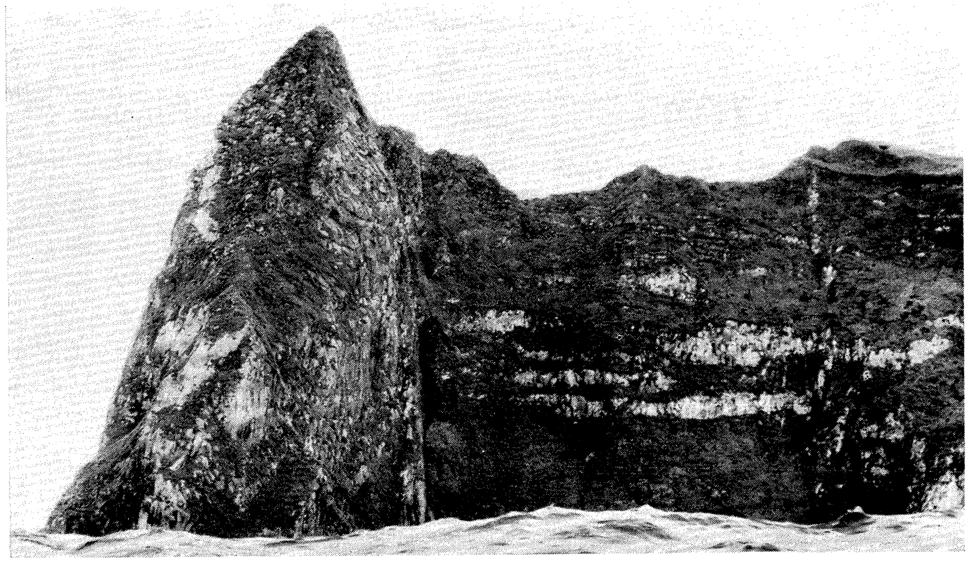


FIGURE 55. South Point: a trachyte dome displaying marked columnar jointing in places; a similar dome, Pyramid Rock, occurs nearby.

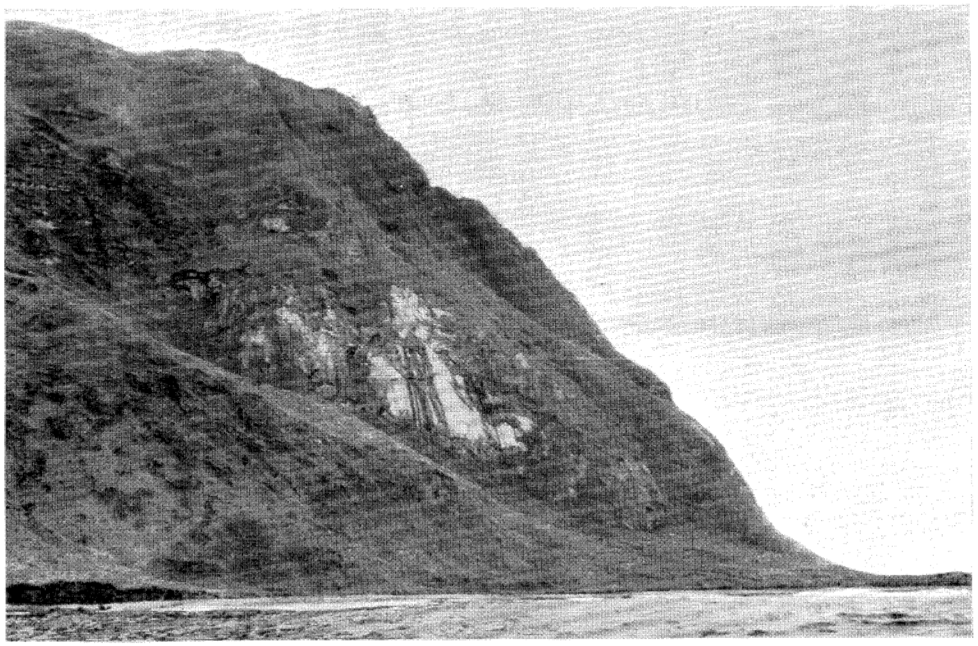


FIGURE 56. The Blenden Hall dome: a trachyte dome in the base of the cliff section behind the low promontory of Blenden Hall; the smooth surface is due to exfoliation weathering and is in contrast with the rugged outline of South Point.

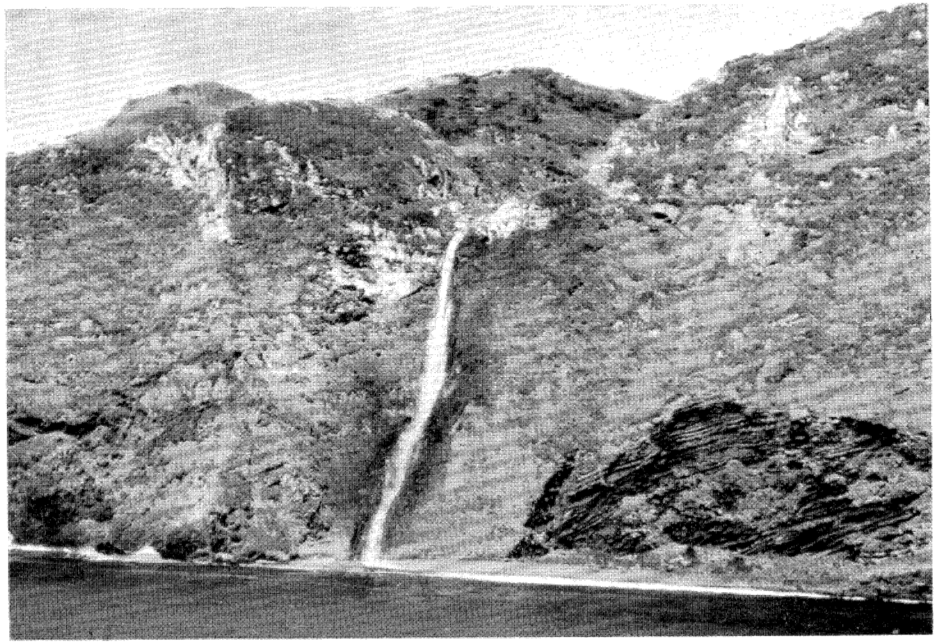


FIGURE 57. The waterfall, Salt Beach: clearly visible in the cliff section is a parasitic centre in which thin basaltic flows are interleaved with pyroclastic debris. Part of a surface cinder cone can be seen outlined against the sky.

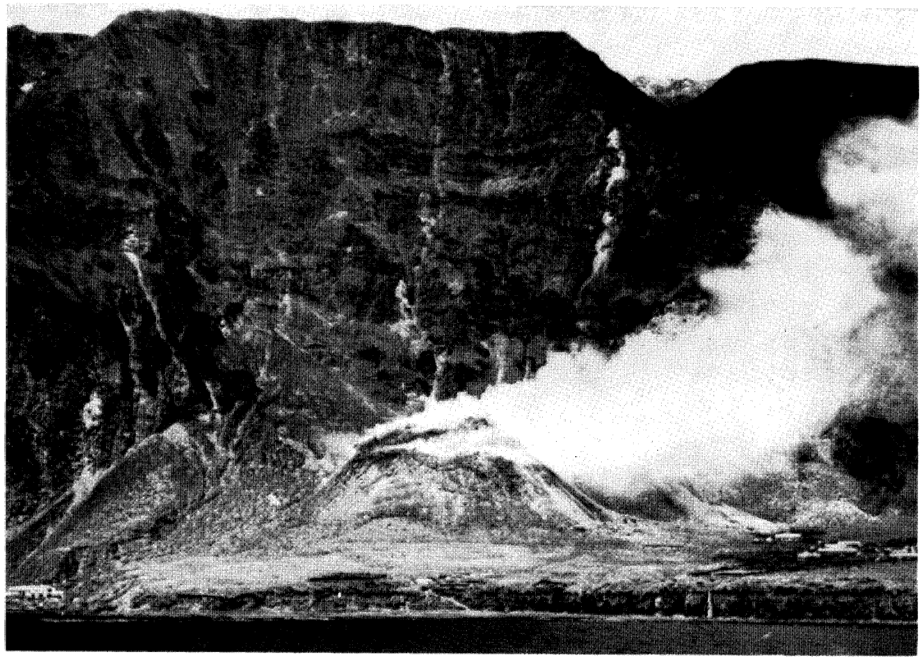


FIGURE 58. 12 October 1961. The initial tholoid from H.M.S. *Leopard*. Official photograph, Crown Copyright reserved.

FIGURE 59. 14 October 1961. The initial tholoid from the village. Official photograph, Crown Copyright reserved.

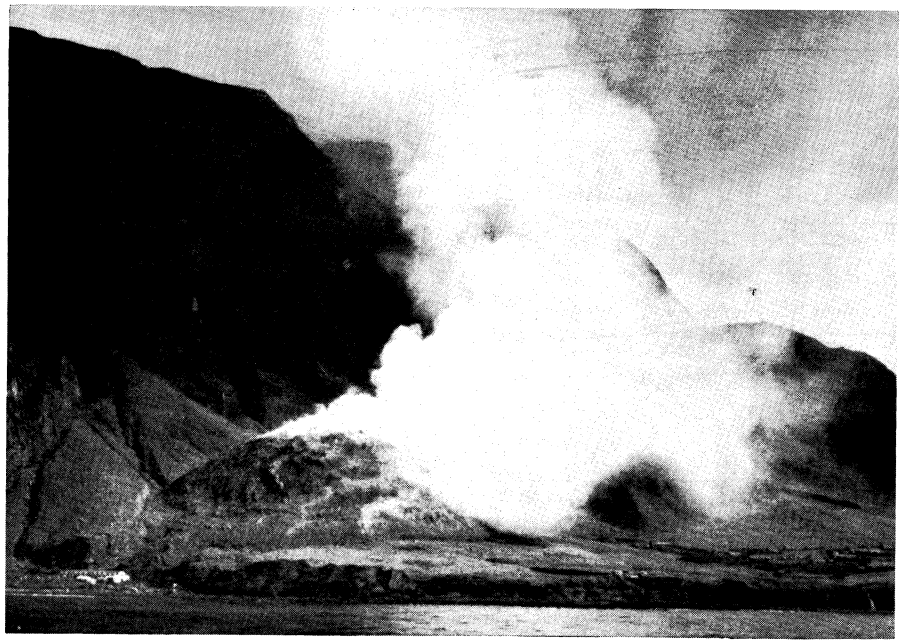


FIGURE 60. 21 October 1961. The tholoid, now nearly 400 ft. high; considerable growth had taken place during the preceding week. Photograph by Captain M. T. Scott, M.V. *Tristania*.

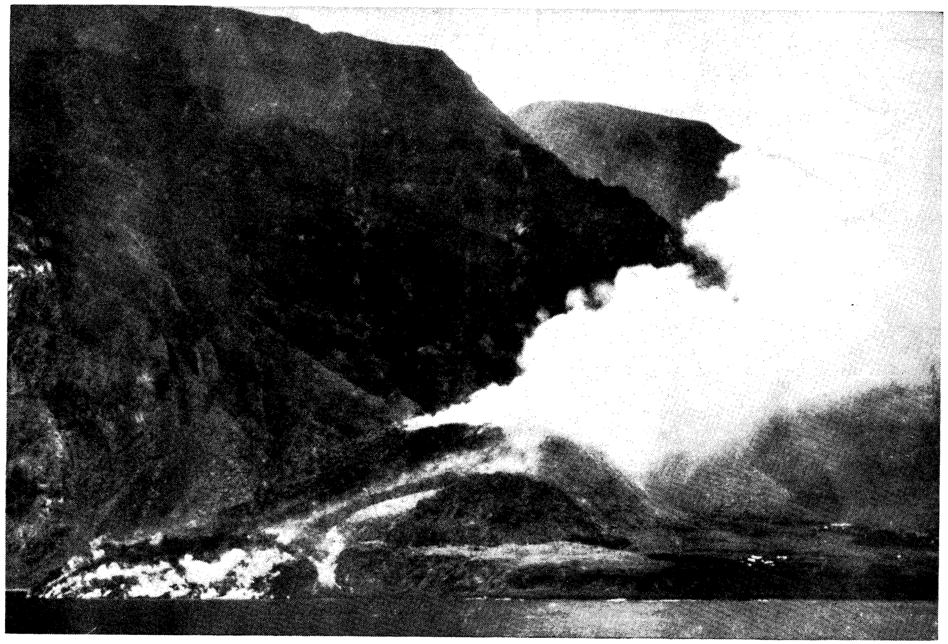


FIGURE 61. 27 October 1961. The tholoid had breached on the seaward side and the lava extended for 100 yards into the sea having engulfed the crawfish canning factory. Photograph by Captain M. T. Scott, M.V. *Tristania*.

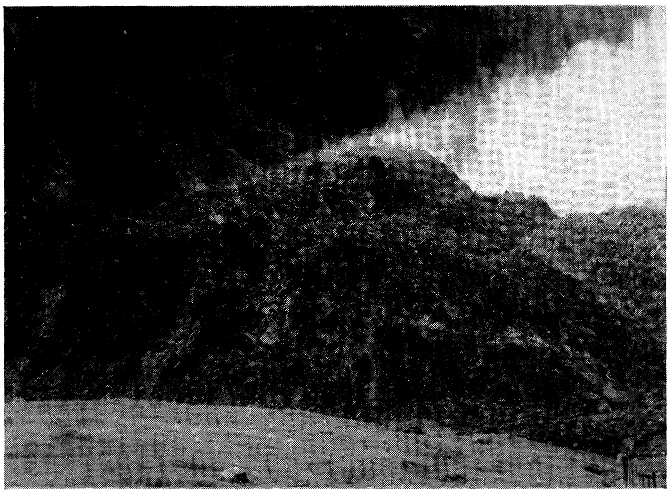


FIGURE 62. The source region from the west: showing the outer wall of the tholoid, the depression of the fosse and the elongated form of the dome. Late February 1962.

FIGURE 63. The western side of the central cone from the fosse. The pinnacles are of reddish blocky lava and less conspicuous scoria. This vent was the source area for all the effusive products of the eruption.

Figure 64. The dome in the early stages of development (early February 1962) from the lava field.

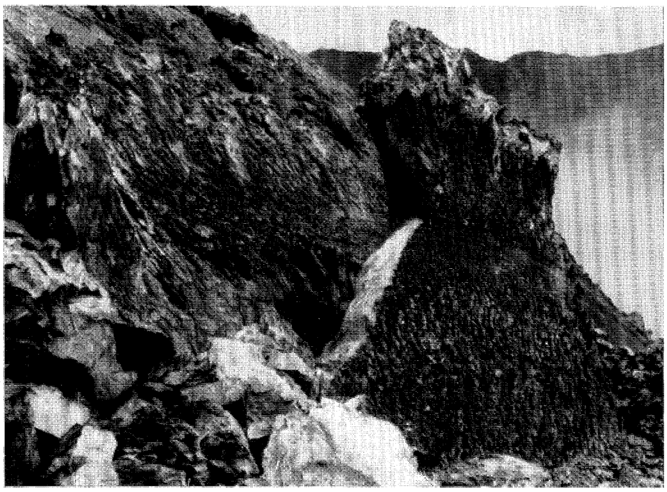


FIGURE 65. The western flank of the dome showing the walls that 'peeled off' during the period of maximum growth. Sharp dentate plications cover the surface of the dome and the wall.

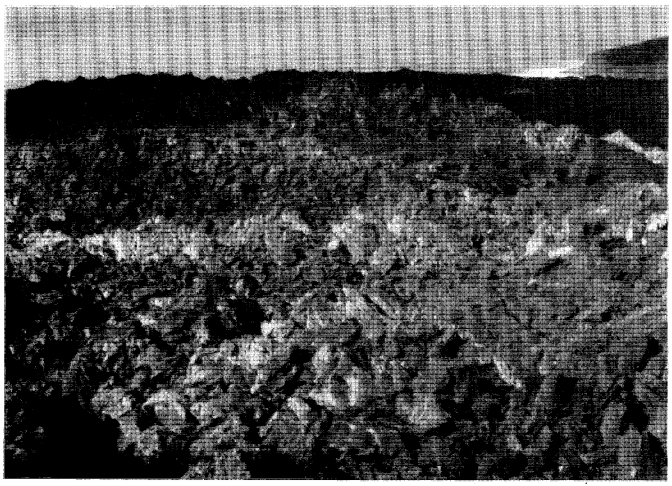


FIGURE 66. The surface of the central flow from the flow dome.

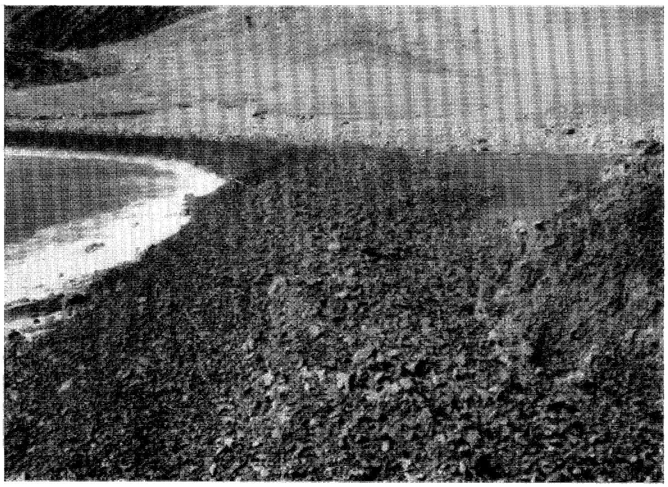


FIGURE 67. The boulder beach or bar formed in four weeks during late February and early March. The bar extends from the eastern margin of the new lava field eastwards to Pigbite and encloses a small lagoon. By September 1962 a similar bar, 200 yards long, had been built up at the western end of the new lava field.

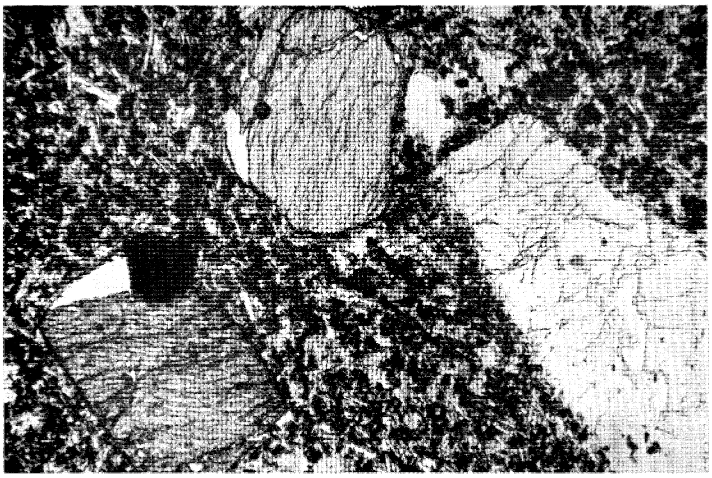


FIGURE 68. *Ankaramite* (114). Base of Main Cliffs east end of Sandy Point. Phenocrysts of olivine, pyroxene and plagioclase set in a groundmass of pyroxene, plagioclase and iron ore. Plane polarized light. (Magn. × 34.)

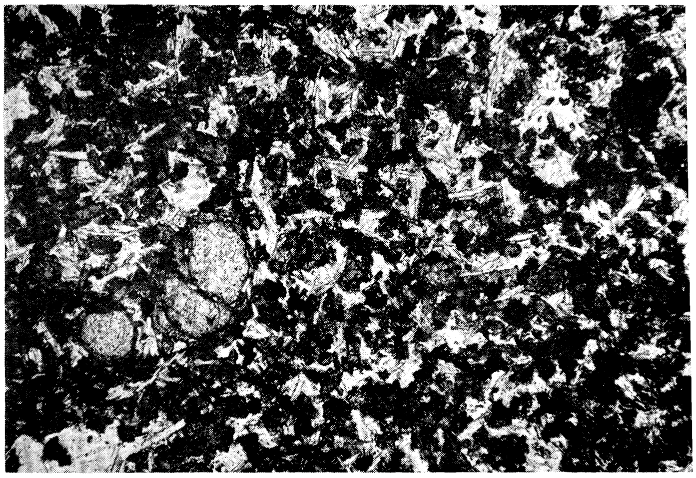


FIGURE 69. *Olivine basalt* (6). Volcanic conduit in Mai Cliffs, 300 yards west of Caves Gulch. Small phenocrys of olivine in a groundmass of plagioclase, pyroxene an iron ore. Plane polarized light. (Magn. × 34.)

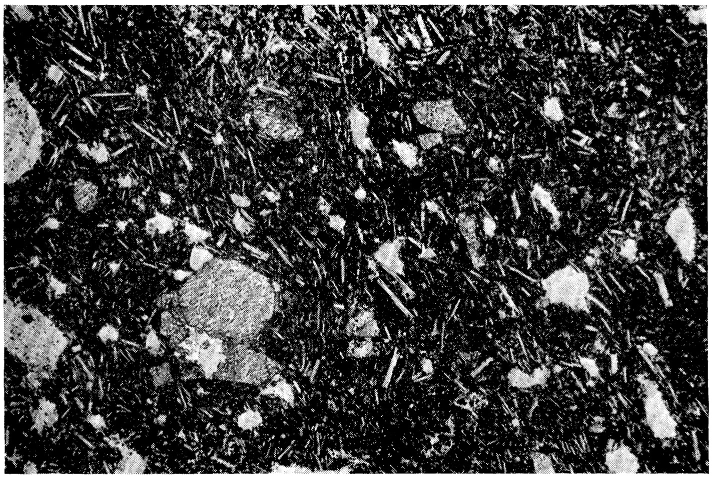


FIGURE 70. *Trachybasalt* (466). Dyke, east side of headland to the east of the waterfall, Inaccessible. Small phenocrysts of olivine in a groundmass of plagioclase, iron ore and pyroxene. Plane polarized light. (Magn. × 34.)

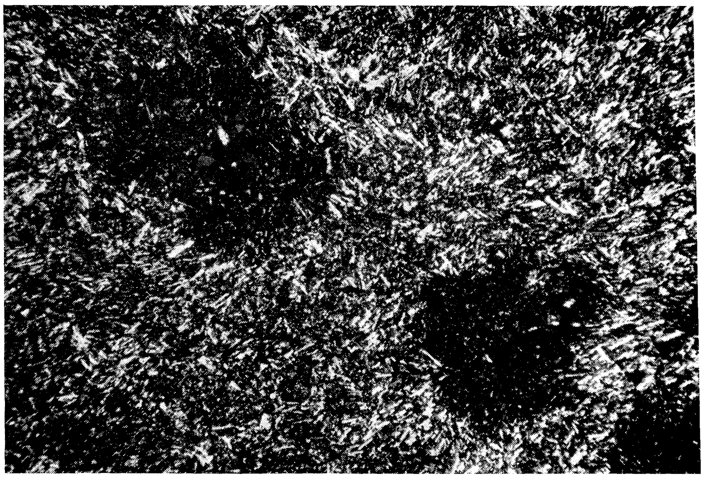


FIGURE 71. *Leucite-bearing trachybasalt* (194). Volcanic necl in Blineye parasitic centre, west end of Stony Beach. Fin grained rock consisting of crystals of plagioclase, pyroxen and iron ore. Leucite forms the mesostasis of the darl spots. Crossed polars. (Magn. × 34.)

FIGURE 72. *Leucite-bearing trachybasalt* (351). Small plug 100 yards east of summit crater lake. Leucite occurring as a cavity infilling. Crossed polars. (Magn. × 135.)

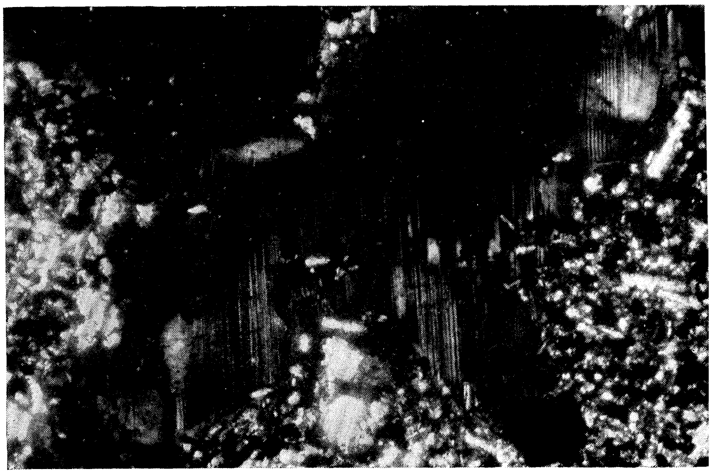


FIGURE 73. *Leucite-bearing trachybasalt* (351). Leucite occurring as the infilling of a small irregular cavity and displaying lamellar twinning. Crossed polars. (Magn. × 135.)

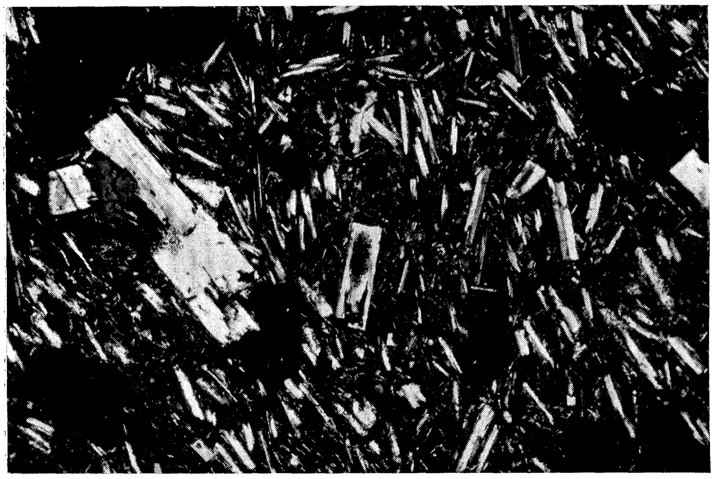


FIGURE 74. *Trachyandesite* (183). Flow from Hill-with-a-hole-in. Phenocrysts of zoned plagioclase An_{60} to An_{37} in sub-parallel orientation and microphenocrysts of pyroxene in a groundmass of plagioclase, pyroxene, alkali feldspar, ore and glass. Crossed polars. (Magn. × 34.)

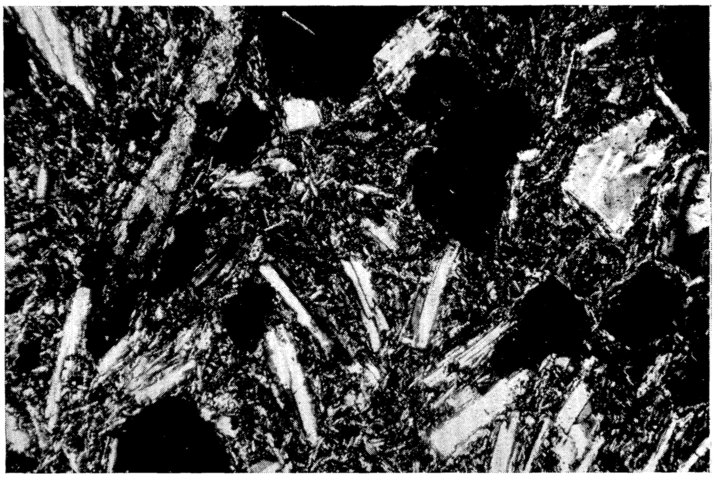


FIGURE 75. *Trachyandesite* (230). Summit of flow lobing south-east from Stony Hill. Phenocrysts of plagioclase An_{60} and basaltic hornblende in a hyalopilitic groundmass of plagioclase laths, aegirine microlites and ore in a turbid mesostasis of alkali feldspar and brown glass. Crossed polars. (Magn. × 34.)

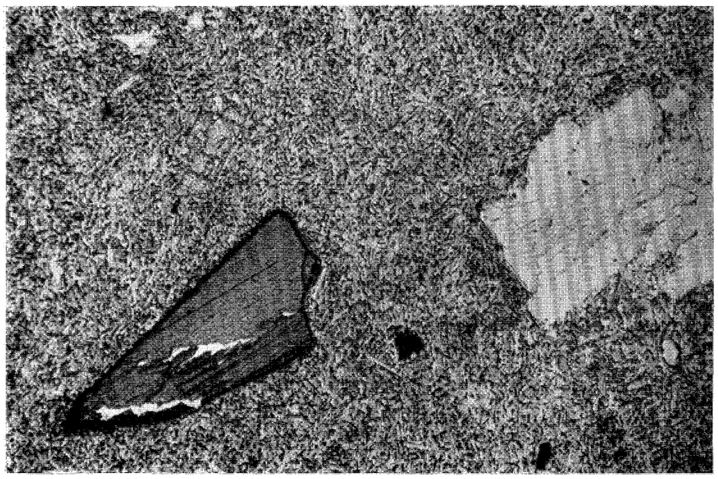


FIGURE 76. *Porphyritic trachyandesite* (572). Lava flow west side of 2nd Ridge-where-the-goat-jumped-off. Phenocrysts of partly resorbed amphibole, plagioclase An_{65} and apatite in a felted groundmass of alkali feldspar, acicular pyroxene and iron ore. Plane polarized light. (Magn. × 34.)

FIGURE 77. *Trachyandesite* (616). Central lava, 1961 Eruptive Centre. Phenocryst of amphibole in a groundmass of sub-parallel laths of zoned plagioclase An_{58} to An_{40}, pyroxene and iron ore. Crossed polars. (Magn. × 34.)

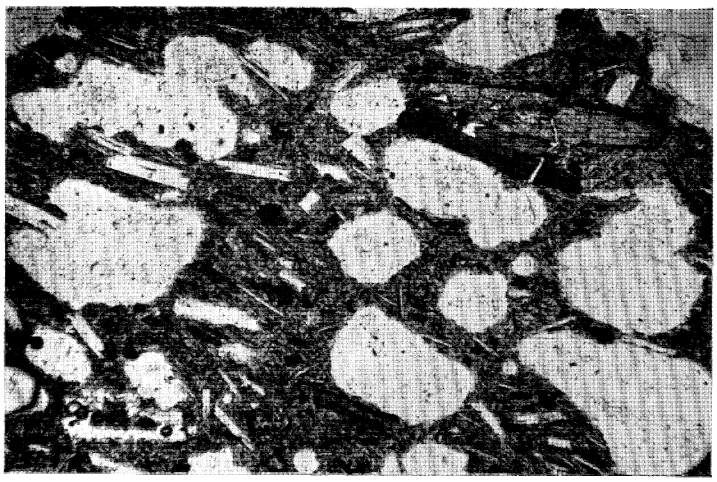


FIGURE 78. *Trachyandesite* (22). Large bomb 50 yards from west flank of 1961 Eruptive Centre. Phenocrysts of basaltic hornblende and microphenocrysts of plagioclase An_{55} in a groundmass consisting of plagioclase and pyroxene microlites and brown glass. Plane polarized light. (Magn. × 34.)

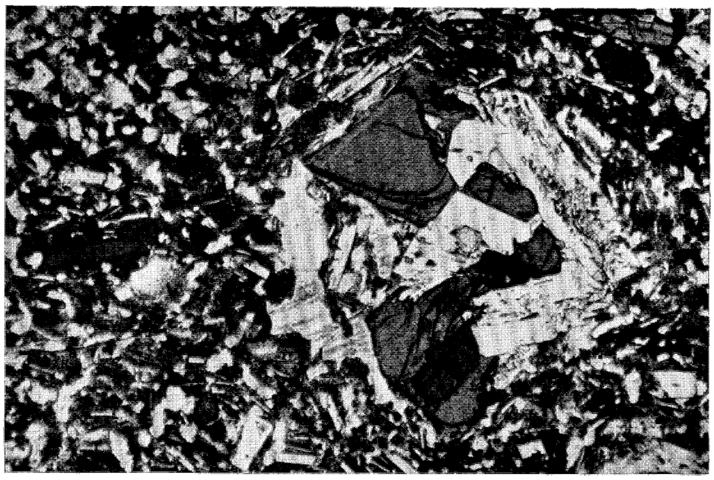


FIGURE 79. *Xenolith in trachyandesite* (518). West flank of dome, 1961 Eruptive Centre. Small xenolith consisting of pyroxene, plagioclase An_{75} and sphene in a trachyandesite consisting of finer-grained feldspar, pyroxene and iron ore. Plane polarized light. (Magn. × 34.)

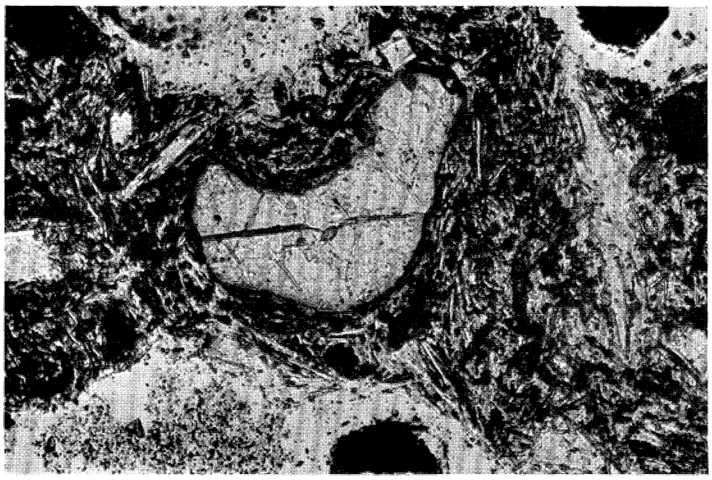


FIGURE 80. *Trachyandesite* (72). Western flow, 1961 Eruptive Centre. A crystal of haüyne, surrounded by pyroxene, feldspar and iron ore. Plane polarized light. (Magn. × 135.)

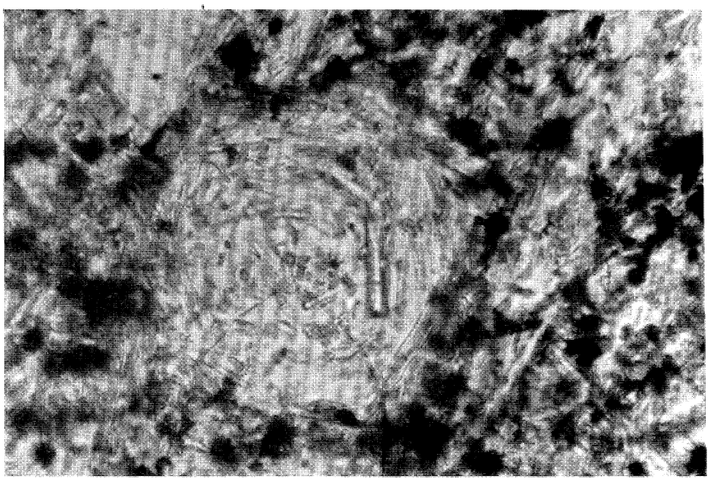


FIGURE 81. *Trachyandesite* (345). A minute rounded grain of leucite containing tangentially arranged rods of pale-green pyroxene. Plane polarized light. (Magn. × 135.)

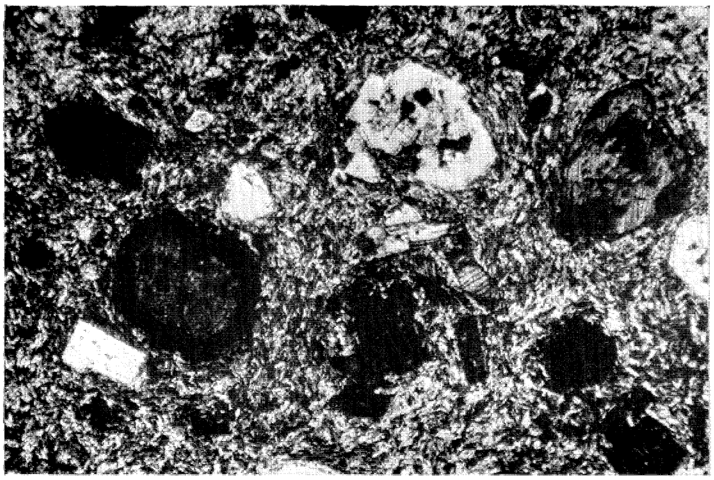


FIGURE 82. *Plagioclase trachyte* (412). 200 yards north-east of North Pond, Nightingale I. Phenocrysts of resorbed amphibole, pyroxene and plagioclase in a groundmass of alkali feldspar and aegirine-augite. Crossed polars. (Magn. × 14.)

FIGURE 83. *Alkali feldspar trachyte* (439). Columnar jointed lava beneath tuff on hardie off Sea hen Rocks, Nightingale I (plate 26). Abundant phenocrysts of alkali feldspar in a groundmass of alkali feldspar, aegirine-augite and iron ore. Crossed polars. (Magn. × 14.)

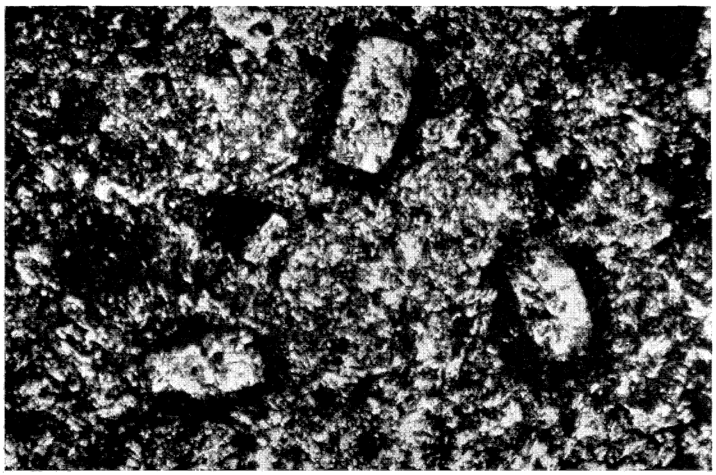


FIGURE 84. *Phonolitic alkali feldspar trachyte* (30). Stock-like mass west of Settlement Quarry. Small phenocrysts of nepheline with a dark alteration rim. The groundmass consists of alkali feldspar, aegirine-augite and iron ore. Crossed polars. (Magn. × 34.)

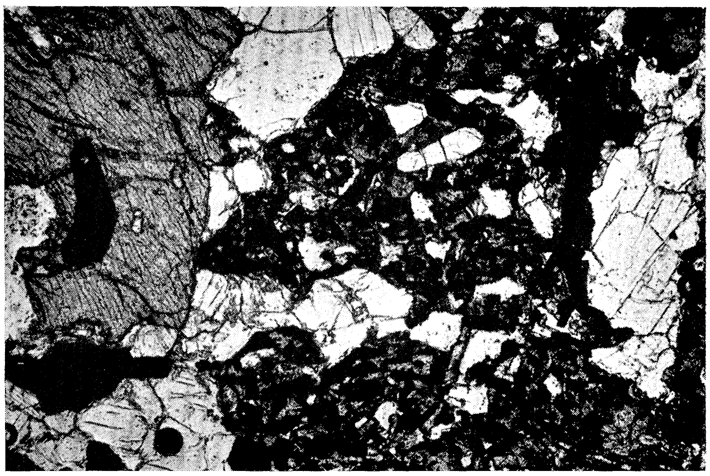


FIGURE 85. *Gabbroic xenolith* (104). In trachybasalt at east end of Sandy Point. Pyroxene, plagioclase and iron ore; the granular mass in the centre of the photograph represents completely altered amphibole. Plane polarized light. (Magn. × 34.)

FIGURE 86. *Gabbroic xenolith* (298). From Hackel Hill lava, 200 yards south of Hackel Hill. Fresh amphibole, plagioclase (labradorite-bytownite range) and clot of apatite. Plane polarized light. (Magn. × 14.)

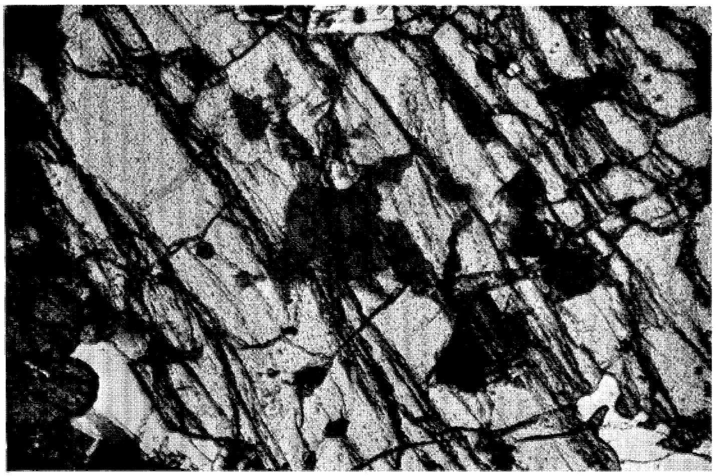


FIGURE 87. *Gabbroic xenolith* (165). From prominent red bluff 600–700 ft. O.D. between West Jews and East Jews Point. Shows clinopyroxene (light coloured) altering to basaltic hornblende (dark). Crossed polars. (Magn. × 34.)

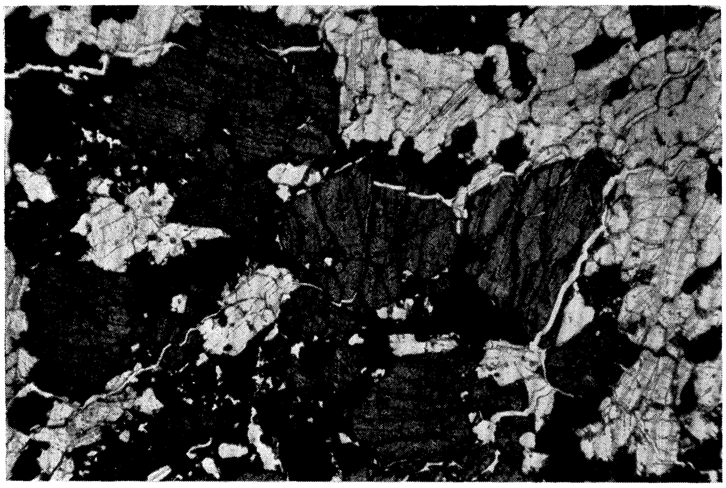


FIGURE 88. *Gabbroic xenolith* (TX5). Locality unknown: collected for R. W. Le M. by Islanders in 1956. Coarsely crystalline pyroxene, plagioclase and iron ore. Plane polarized light. (Magn. × 14.)

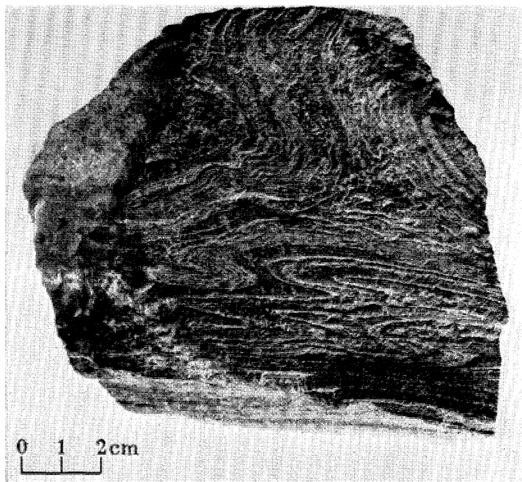


FIGURE 89. *Flow-banded trachybasalt* (117). Sandy Point, 100 yards north of east end of Sandy Point Gulch. Weathered surface: flow seems to be due largely to concentration of femic constituents, obscure when examined under microscope.

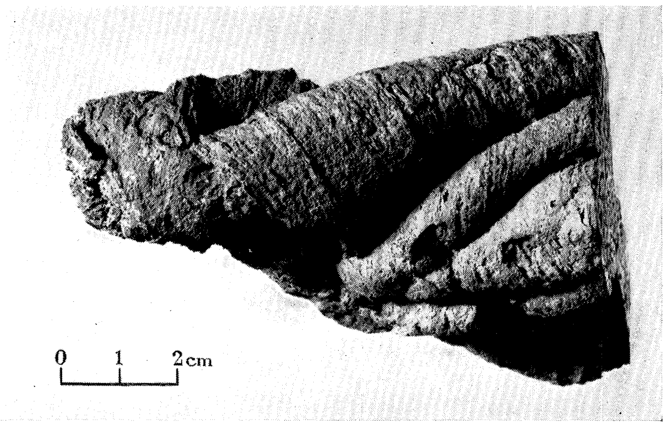


FIGURE 90. Ropy surface to thin basalt flow (F 10002, Leeds Collection). Fems Gulch 260 yards from Snell's Beach. Shows convolute form of the 'ropes' and the ribbing on the surface.

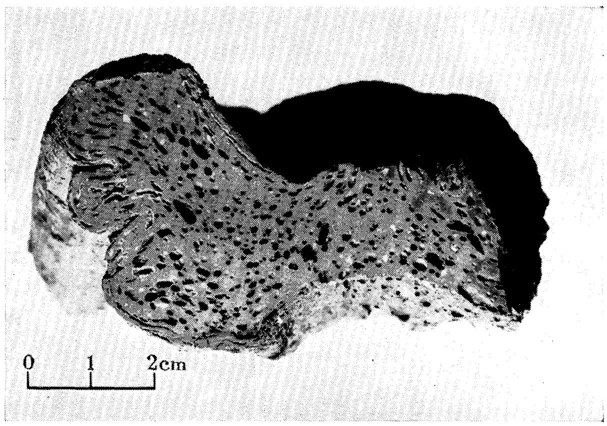
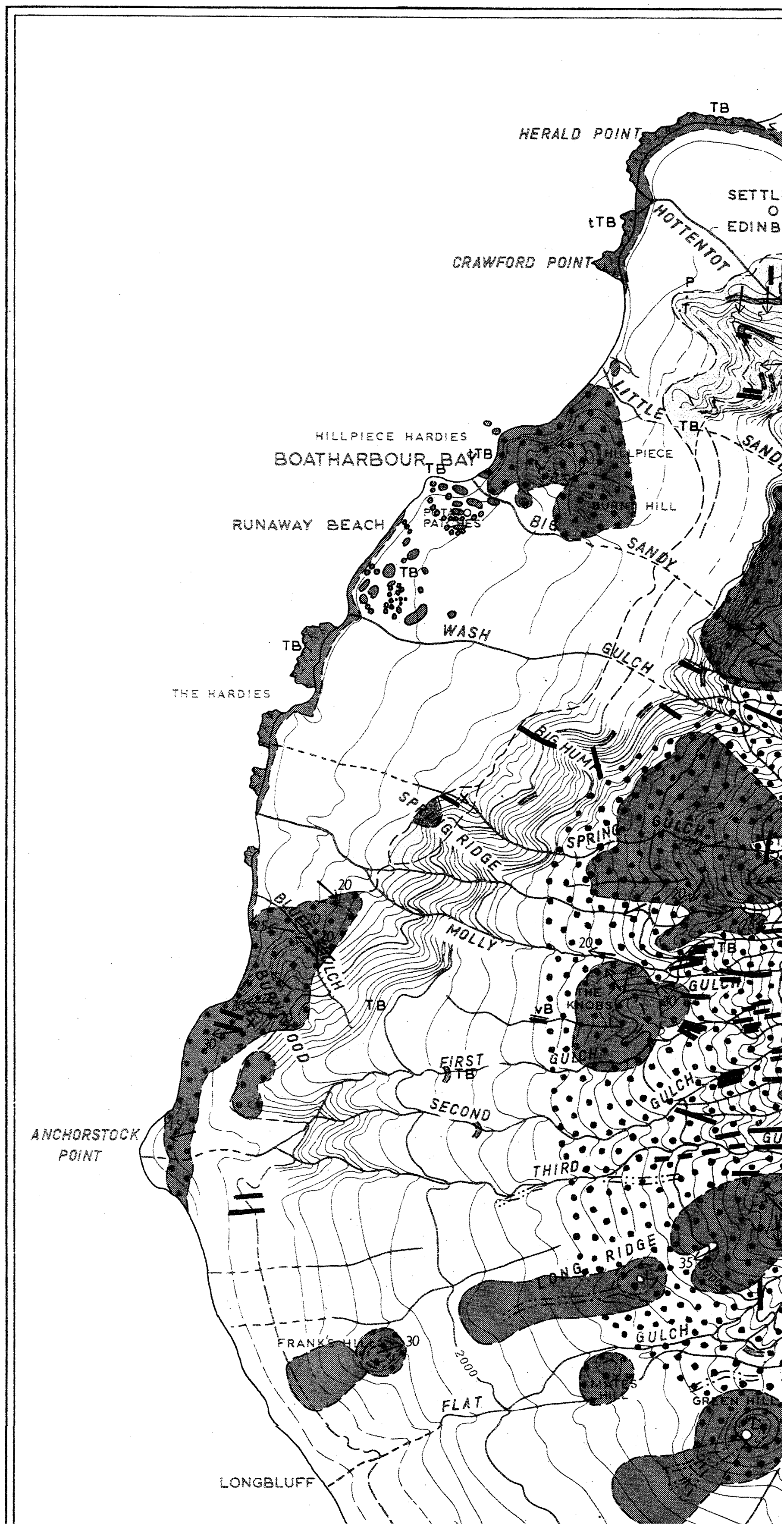
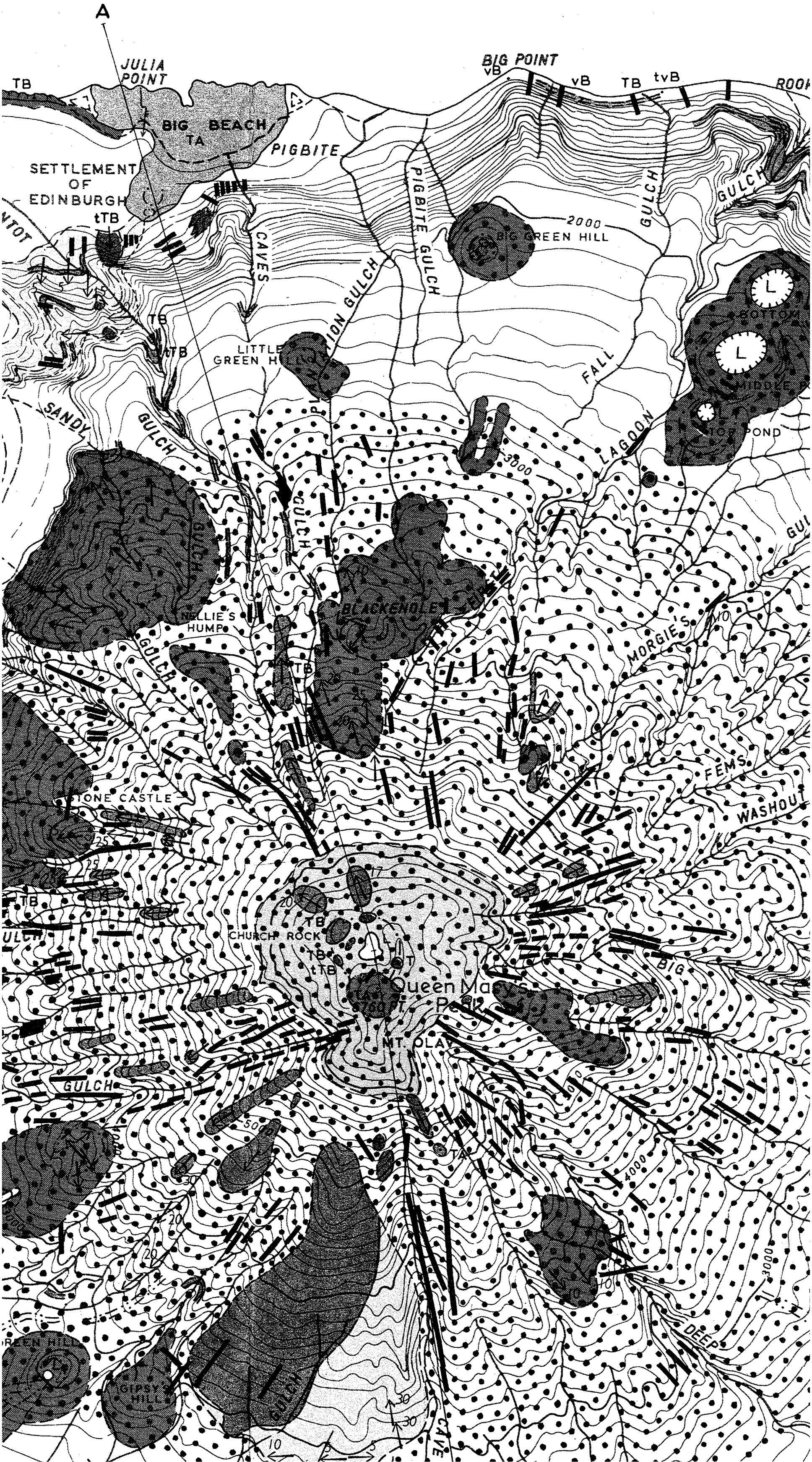


FIGURE 91. As figure 90. Cross-section through ropy lava showing the orientation of vesicles.

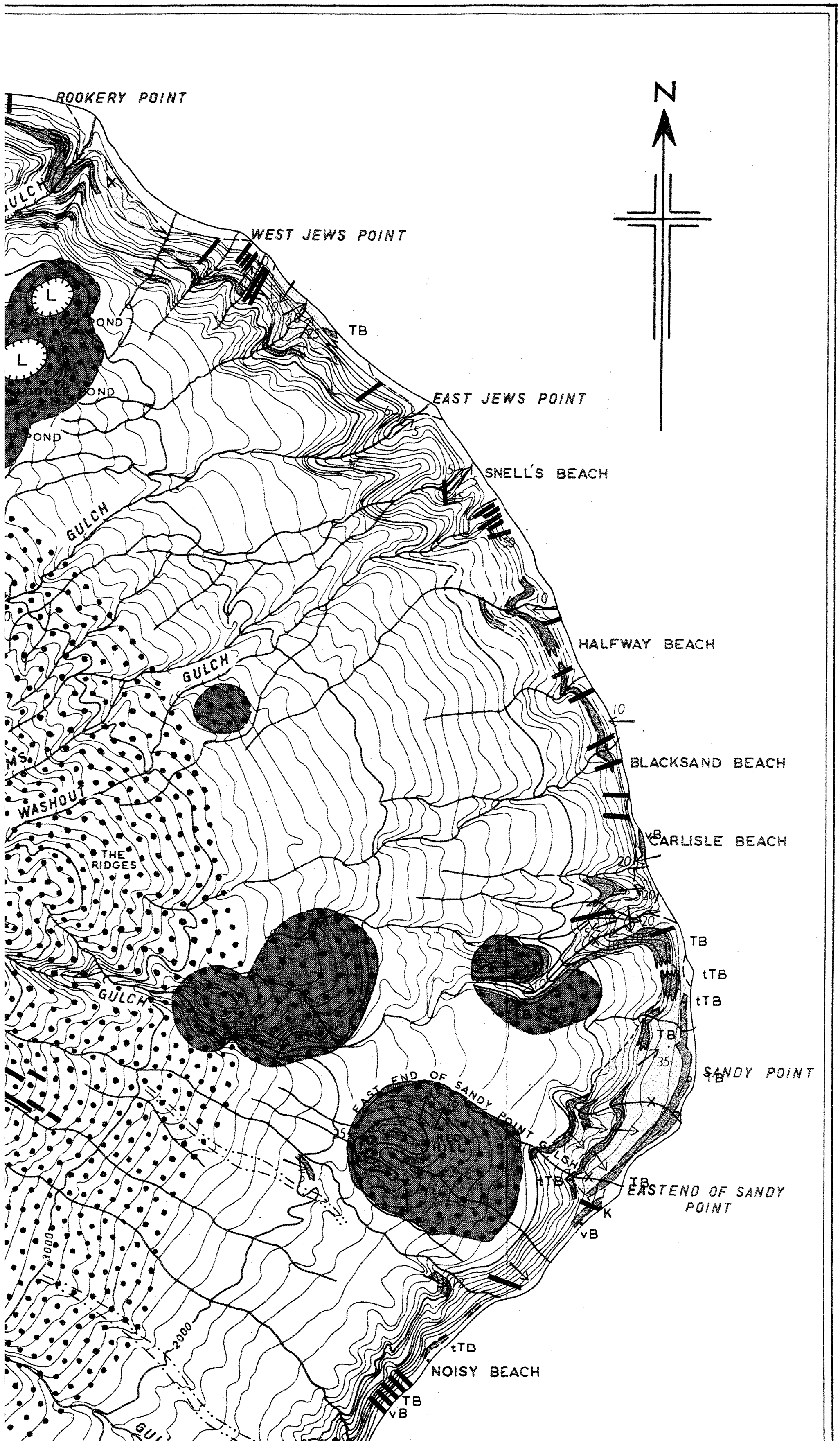


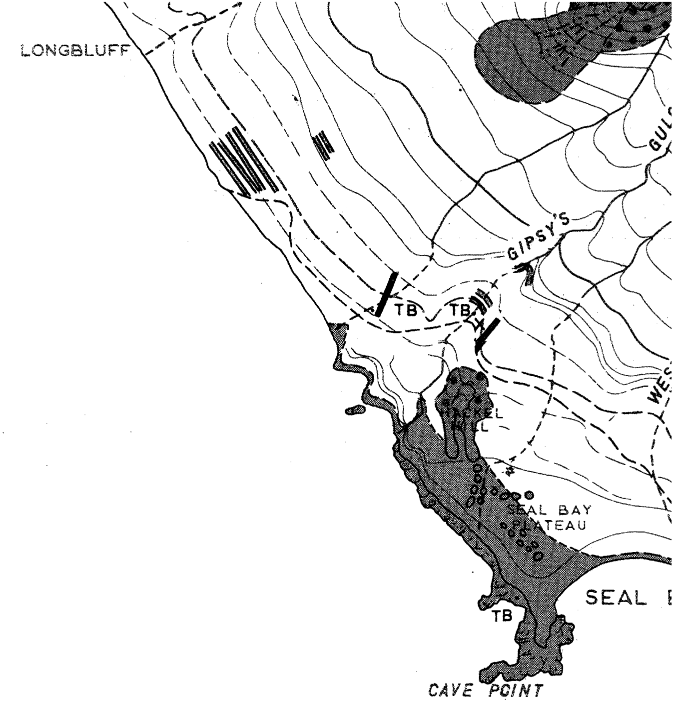
HERALD POINT
TB
SETTL
O
EDINB
tTB
HOTTENTOT
CRAWFORD POINT
P
LITTLE
TB
SAND
HILLPIECE HARDIES
BOATHARBOUR BAY
TB
tTB
HILLPIECE
BURNT HILL
RUNAWAY BEACH
POTATO PATCHES
BIG
SANDY
TB
WASH
GULCH
TB
THE HARDIES
BIG HUMP
SPRING RIDGE
SPRING
GULCH
20
MOLLY
GULCH
BURNTWOOD
TB
THE KNOBS
vB
GULCH
FIRST
TB
SECOND
GULCH
ANCHORSTOCK POINT
THIRD
LONG RIDGE
35
GULCH
FRANK'S HILL
30
2000
FLAT
GREEN HILL
LONGBLUFF

GEOLOGICAL MAP OF
ıa TRISTAN DA CUNHA

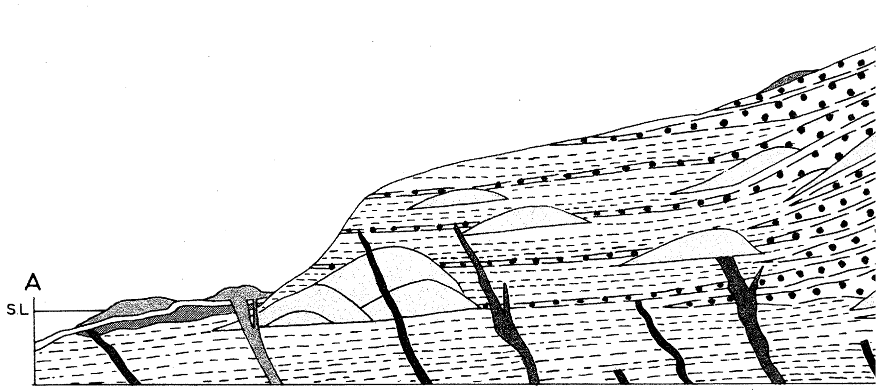


IHA


ROOKERY POINT
GULCH
WEST JEWS POINT
BOTTOM POND
MIDDLE POND
POND
L
L
TB
EAST JEWS POINT
SNELL'S BEACH
GULCH
HALFWAY BEACH
GULCH
BLACKSAND BEACH
WASHOUT
CARLISLE BEACH
vB
THE RIDGES
TB
tTB
tTB
GULCH
TB
SANDY POINT
TB
EAST END OF SANDY POINT GULCH
RED HILL
TB
tTB
EASTEND OF SANDY POINT
K
vB
3000
2000
tTB
NOISY BEACH
TB
vB
N



DIAGRAMMATIC CROSS SECTION
Radial dykes omitted.



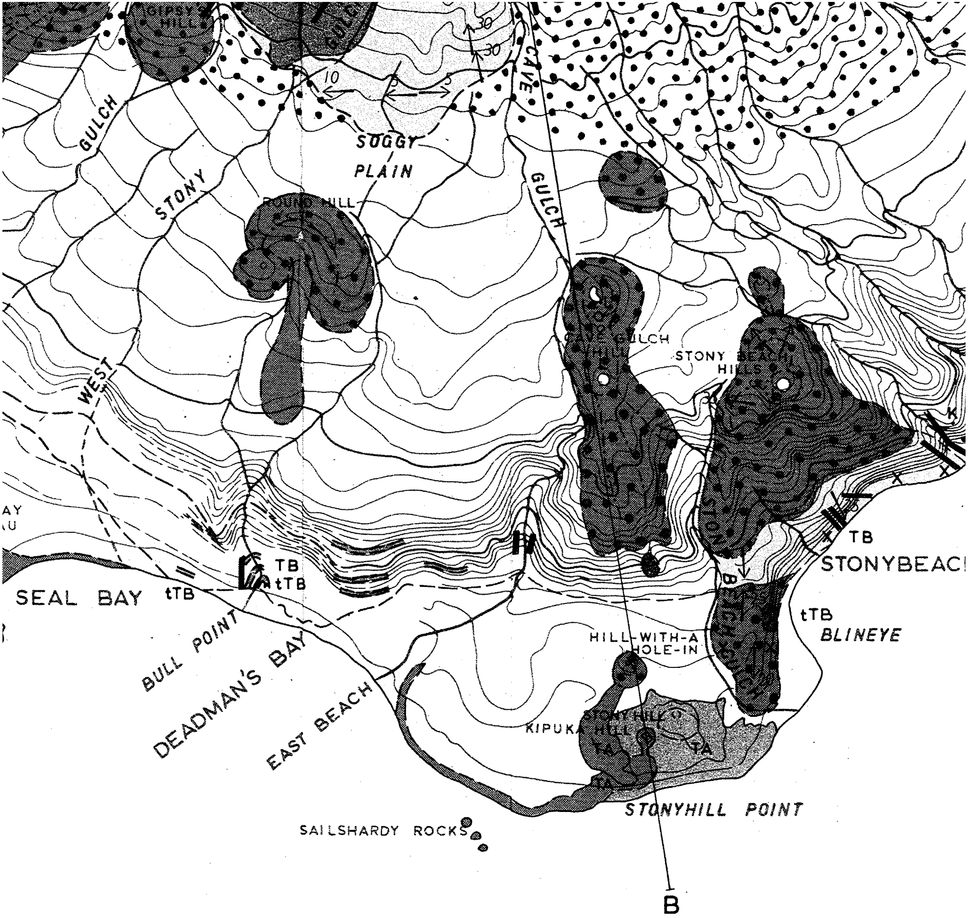
Recent trachyandesite eruptions. {*Stony Hill* / *Settlement (1961)*}

Alluvium. Mainly outwash deposits.

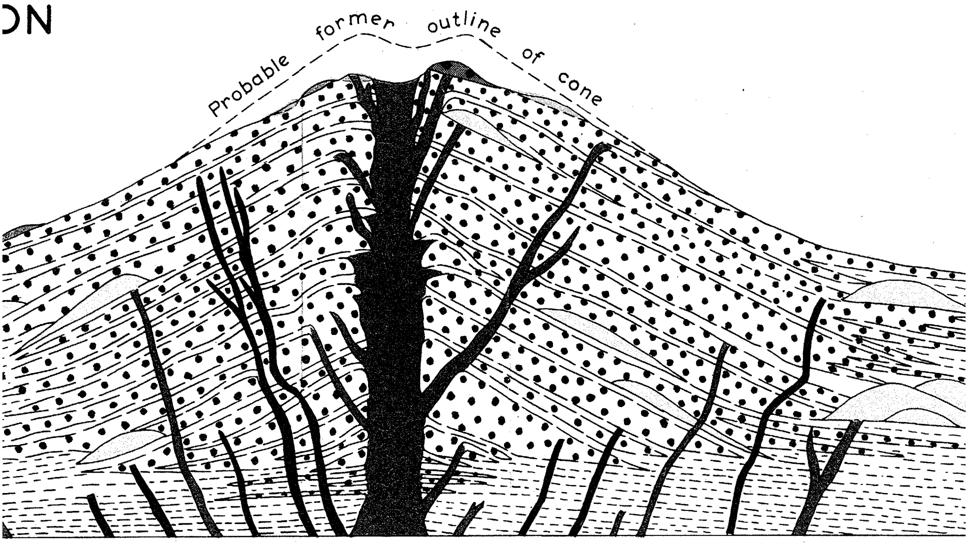
Surface cinder cones.

Lavas from surface cinder cones.

Peak cinder cone.



ON



LEGEND

1961)

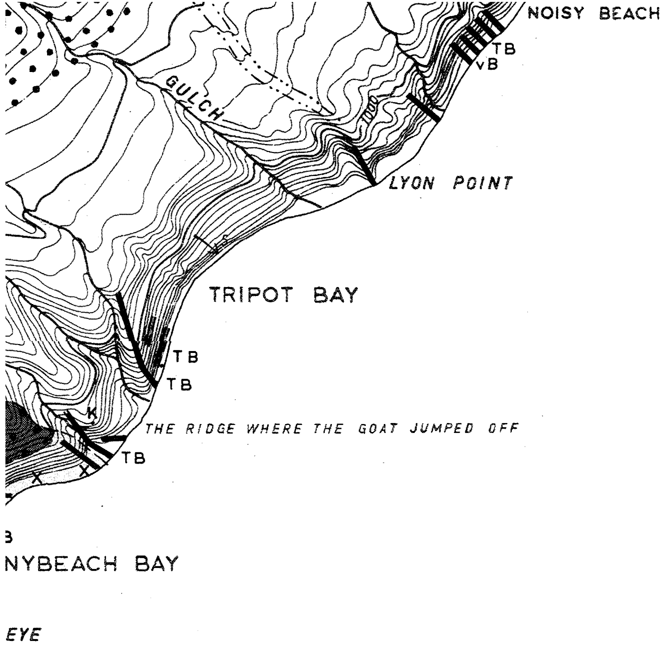
Dip, mainly depositional, on lavas and pyroc

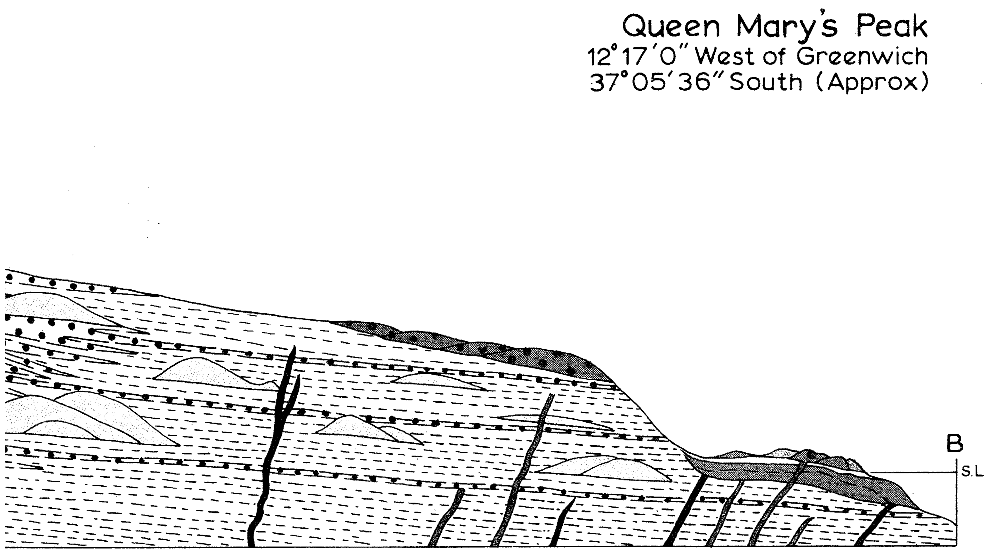
Margin of crater.

Margin of volcanic vent.

Crater lake.

Geological boundary





pyroclastic deposits.

Basalt _ B

Olivine Basalt _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ vB

Leucitic Olivine Basalt _ _ _ _ _ _ _ _ _ _ tvB

Trachybasalt _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ TB

Leucitic Trachybasalt _ _ _ _ _ _ _ _ _ _ _ tTB

Ankaramite _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ K

Lavas from surface cinder cones.

Peak cinder cone.

Main volcanic sequence:- Predominantly pyroclastic.
Predominantly lava.

Pyroclastic centres within main sequence.

Prominent lava flows.

Intrusive masses.

Dykes, near vertical unless indicated otherwise.

stic.

Crater lake.

Geological boundary.

Inferred geological boundary.

Indefinite geological boundary.

Lava channels

HORIZONTAL AND VERTICAL SCALE

1 0 1

MILES

Leucitic Trachybasalt ___________ tTB

Ankaramite ______________________ K

Leucitic Ankaramite _____________ tK

Trachyandesite __________________ TA

Trachyte ________________________ T

Phonolite _______________________ P

Plutonic Xenoliths ______________ X

ALE

2

The 1961 Eruption; photograph taken from the helicopter of H.M.S. *Protector* on 20 March 1962. Crown Copyright.

Table 5. Name, type, locality, analyst (A) or reference (R) of all analyzed rocks

number	name	type	locality	analyst or reference
			Tristan	
114	ankaramite	lava	base of Main Cliffs; east end of Sandy Point	J. R. Baldwin (A)
62·1	olivine basalt	lava	Sandy Point	J. C. Dunne (1941, p. 62) (R & A)
6	alkali olivine basalt	neck	300 yards west of Caves Gulch. 100 ft. O.D.	J. R. Baldwin (A)
64·4	trachybasalt	—	Tristan	W. Campbell Smith (1930) (R)
504	trachybasalt	dyke	East Molly Gulch. 4000 ft.	I. D. Bothwell (A)
64·3	trachybasalt	—	Tristan	W. Campbell Smith (1930) (R)
364	trachybasalt	lava	Hottentot Gulch. 5400 ft. O.D.	J. R. Baldwin (A)
20	trachybasalt	block	small cinder cone immediately north of Big Sandy Gulch	M. H. Kerr (A)
21	trachybasalt	lava	west headland of Boat Harbour Bay	M. H. Kerr (A)
369	trachybasalt	lava	north end of Stony Beach. 1800 ft. O.D.	M. H. Kerr (A)
622	trachybasalt	lava	'Pillow Lavas' foreshore immediately west of 1961 lava	M. H. Kerr (A)
64·2	doleritic olivine basalt	dyke	behind Settlement	J. C. Dunne (1941, p. 64) (R & A)
117	flow-banded trachybasalt	lava	Sandy Point, 100 yards north of East End Gulch	J. R. Baldwin (A)
347	trachybasalt	lava	Pigbite Gulch. 60 ft. O.D.	J. R. Baldwin (A)
619	trachybasalt	bomb	inside crater wall, Frank's Hill	I. D. Bothwell (A)
351	leucite-bearing trachybasalt	plug	100 yards east of summit crater lake. 6550 ft. O.D.	J. R. Baldwin (A)
194	leucite-bearing trachybasalt	neck	Blineye parasitic centre	M. H. Kerr (A)
125	leucite-bearing trachybasalt	lava	Noisy Beach, ½ mile north of Lyon Point. 40 ft. O.D.	J. R. Baldwin (A)
74·2	trachybasalt	lava	First Lagoon Gulch	J. C. Dunne (1941, p. 74) (R & A)
230	trachyandesite	lava	Stony Hill; south-east lava	J. R. Baldwin (A)
232	trachyandesite	spine	Stony Hill; prominent spine near summit	J. R. Baldwin (A)
80·1	trachyandesite	lava	First Lagoon Gulch. 4000 ft. O.D.	J. C. Dunne (1941, p. 80) (R)
657	trachyandesite	bomb	1961 eruption; glassy bomb, 100 yards west of tholoid	M. H. Kerr (A)
518	trachyandesite	tholoid	1961 eruption; west flank of tholoid, 40 yards from summit	M. H. Kerr (A)
617	trachyandesite	lava	1961 eruption; central flow	M. H. Kerr (A)
572	porphyritic trachyandesite	lava	west side of Ridge-where-the-goat-jumped-off. 2500 ft. O.D.	I. D. Bothwell (A)
627	trachyandesite	lava	1961 eruption; north-east extremity of lava field	M. H. Kerr (A)
80·5	trachyandesite	loose-block (lava)	Cave Gulch. 4550 ft. O.D.	J. C. Dunne (1941, p. 80) (R & A)
560	plagioclase trachyte	plug	south-eastern flank of Peak	I. D. Bothwell (A)
86·3	sodalite plagioclase trachyte	plug	within summit crater	J. C. Dunne (1941, p. 86) (R)
30	phonolitic alkali feldspar trachyte	plug	400 yards west of Settlement Quarry, foot of Main Cliffs	I. D. Bothwell (A)
31	alkali feldspar trachyte	plug	10 yards east of specimen 30	I. D. Bothwell (A)
86·5	sodalite trachyte	—	Stony Beach	J. C. Dunne (1941, p. 86) (R)
			Nightingale	
1713·4	'phonolitic tufa' (trachyandesite)	agglomerate	north-east of Nightingale, opposite Middle Island	A. Renard (1889) (R)
401	trachybasalt	dyke	cutting agglomerate north end of High Ridge	M. H. Kerr (A)
74·1	trachybasalt	dyke	Middle Island	J. C. Dunne (1941, p. 74) (R)
74·3	trachybasalt	—	north-east peak, Middle Island	W. Campbell Smith (1930) (R)
74·4	trachybasalt	dyke	Middle Island	W. Campbell Smith (1930) (R)
80·4	trachyandesite	—	eastern section, Nightingale Island	J. C. Dunne (1941, p. 80) (R)
80·6	tephritic trachyte	—	Middle Island	W. Campbell Smith (1930) (R)
412	trachyandesite	intrusive mass	200 yards north-east of North Pond	M. H. Kerr (A)
420	plagioclase trachyte	intrusive mass	north end of High Ridge	M. H. Kerr (A)
86·1	biotite trachyte	intrusive mass	Stoltenhoff Island	J. C. Dunne (1941, p. 86) (R & A)
439	alkali feldspar trachyte	lava	Hardies off Sea Hen Rocks	M. H. Kerr (A)
86·4	sodalite trachyte	—	east side of Nightingale Island	J. C. Dunne (1941, p. 86) (R)
			Inaccessible	
88·1	essexitic gabbro	dome	Blenden Hall	J. C. Dunne (1941, p. 88) (R & A)
466	trachybasalt	dyke	Headland, east of waterfall, Salt Beach	I. D. Bothwell (A)
64·1	olivine basalt	—	West Point	J. C. Dunne (1941, p. 64) (R)
70·3	mugearite	dyke	South Point	J. C. Dunne (1941, p. 70) (R & A)
70·1	mugearite	dyke	Blenden Hall	W. Campbell Smith (1930) (R)
70·2	mugearite	vent	Blenden Hall	W. Campbell Smith (1930) (R)
80·2	trachyandesite	thick flow	western section above Blenden Hall	J. C. Dunne (1941, p. 80) (R & A)
80·3	trachyandesite	thick flow	western section above Blenden Hall	J. C. Dunne (1941, p. 80) (R & A)
86·2	biotite trachyte	plug	central portion of Blenden Hall Dome	J. C. Dunne (1941, p. 86) (R & A)

Table 7. Major element content in parts per thousand of metal: spectrographic analyses of trace element content in parts per million

	Tristan																								Nightingale				Inaccessible
specimen no.	114	6	504	364	20	21	369	622	117	347	619	351	194	125	230	232	657	518	617	572	627	560	30	31	401	412	420	439	466
Si	201	198	213	214	217	215	215	215	215	217	216	220	227	231	252	253	257	255	256	253	256	271	279	284	227	268	271	291	217
Ti	22	25	20	22	19	17	13	17	21	22	21	21	18	19	11	11	9	10	10	10	10	7	3	3	16	10	7	2	16
Al	64	75	97	88	88	90	89	90	94	85	96	92	95	94	101	103	104	102	101	106	105	103	104	108	94	90	95	108	94
Fe^{3+}	39	41	17	26	29	26	53	18	32	26	22	21	26	18	24	18	11	34	22	14	21	12	17	16	18	45	20	2	23
Fe^{2+}	64	66	65	57	57	58	42	65	48	54	52	52	40	44	24	26	26	9	23	26	21	17	16	3	40	2	18	7	56
Mn	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mg	62	40	28	29	28	29	29	28	25	28	28	26	20	21	10	10	9	9	9	11	7	6	2	1	21	12	7	0	35
Ca	90	85	71	71	67	68	67	67	69	68	67	64	61	54	45	44	41	41	40	37	40	24	9	10	58	27	23	9	66
Na	18	21	31	29	28	30	28	30	32	29	35	30	35	37	37	39	44	45	45	45	45	48	42	46	31	40	45	44	29
K	12	17	25	26	25	26	23	26	26	26	27	28	28	32	38	38	42	41	41	46	43	44	55	56	27	43	50	59	22
Fe (total)	103	107	82	83	86	84	95	83	80	80	74	73	66	62	48	44	37	43	45	40	42	29	33	19	58	47	38	9	79
differentiation index	22·6	27·9	39·7	41·8	43·0	43·0	43·1	43·3	43·7	45·0	45·0	45·9	52·2	55·9	65·2	65·7	70·1	70·4	70·7	71·2	71·5	79·5	85·5	88·0	49·6	76·1	81·0	90·3	39·3
Nb	20	35	100	110	120	130	95	130	85	110	100	80	160	120	160	160	140	170	150	130	140	130	160	230	130	140	140	130	110
Mo	< 3	3	4	5	6	6	5	7	5	6	4	4	9	5	5	4	6	6	6	7	6	7	< 3	4	5	6	10	3	5
Zr	100	200	300	300	350	350	300	350	300	300	300	300	400	350	350	400	350	350	350	300	350	350	500	500	350	500	550	550	300
Ga	25	27	27	28	28	28	27	35	27	27	28	27	29	28	27	28	29	27	28	27	26	27	29	26	29	35	35	30	24
Cr	250	65	—	—	30	45	18	30	—	—	—	—	—	17	—	12	—	—	—	—	—	—	—	—	—	17	16	—	20
V	400	400	200	400	190	180	200	200	200	300	170	280	250	200	130	130	95	100	120	75	110	50	16	20	200	75	75	10	200
Y	10	15	50	40	60	55	40	60	30	40	45	25	50	40	45	50	40	55	45	45	45	35	20	40	40	35	15	10	50
La	< 100	110	190	200	200	200	180	250	170	200	170	160	250	180	250	250	200	250	200	200	200	190	120	250	200	180	< 100	100	180
Be	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	13	—	—	—	—	—
Ni	150	50	—	—	—	10	—	10	—	—	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	45	—	—	80
Co	50	40	18	25	20	20	20	25	14	20	18	15	14	10	—	—	—	—	—	—	—	—	—	—	12	10	—	—	—
Mn	550	1100	1600	1600	1800	1800	1600	1700	1500	1500	1500	1300	1800	1400	1700	1700	1500	1800	1500	1300	1600	1200	1500	1900	1500	1200	1000	650	1600
Sr	700	1000	1200	1600	800	1100	1100	900	1100	1400	1100	1100	1100	1500	1200	1300	1300	1400	1500	1000	1400	650	40	55	1000	650	750	180	800
Pb	< 10	10	18	11	12	18	18	21	15	8	35	10	16	10	17	15	14	16	17	22	14	28	24	25	16	14	17	18	32
Ba	700	750	1000	1200	800	1000	950	850	950	1000	950	1000	950	1200	1100	1100	1200	1300	1400	1100	1300	1000	20	25	950	700	700	160	850
Li	< 4	4	10	7	4	4	< 4	6	10	7	6	6	< 4	10	12	11	10	12	13	12	13	15	15	20	8	8	15	9	8
Rb	90	110	300	170	180	170	110	170	110	160	180	110	220	190	200	200	230	220	210	270	260	350	400	280	150	220	270	250	170
(Ga/Al) × 10^3	0·39	0·36	0·28	0·32	0·32	0·31	0·30	0·39	0·29	0·32	0·29	0·28	0·31	0·30	0·27	0·27	0·28	0·27	0·28	0·25	0·25	0·26	0·28	0·24	0·31	0·39	0·37	0·28	0·26
(V/Mg) × 10^3	6·4	10	7·1	13·8	6·8	6·2	6·9	7·1	8	10·7	6·1	10·8	12·5	9·5	13	13	10·6	11·1	13·3	6·8	16	8·3	8	20	9·5	6·2	10·7	—	5·7
(Ni/Mg) × 10^3	2·4	1·2	—	—	—	0·4	—	0·4	—	—	0·4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3·7	—	—	2·3
(Co/Mg) × 10^3	0·8	1·0	0·6	0·9	0·7	0·7	0·7	0·9	0·6	0·7	0·6	0·6	0·7	0·5	—	—	—	—	—	—	—	—	—	—	0·6	0·8	—	—	1·0
Fe/Mg	1·66	2·7	2·9	2·9	3·1	2·9	3·3	3·0	3·2	2·9	2·6	2·8	3·3	3·0	4·8	4·4	4·1	4·8	5·0	3·6	6	4·8	16	19	2·8	3·9	5·4	—	2·3
(V/Fe) × 10^3	3·9	3·7	2·4	4·8	2·2	2·2	2·1	2·4	2·5	3·7	2·3	3·8	3·8	2·9	2·7	3·0	2·6	2·3	2·7	1·9	2·6	1·7	0·5	1·1	3·4	1·6	2·0	1·1	2·5
(Mn/Fe) × 10^3	5·3	10·3	20	19	21	22	17	21	19	19	20	18	37	23	35	39	41	42	33	32	38	41	45	100	26	25	26	72	20
(Y/Ca) × 10^3	—	0·2	0·7	0·6	0·9	0·8	0·6	0·9	0·4	0·6	0·7	0·4	0·8	0·7	1·0	1·1	1·0	1·3	1·1	1·2	1·1	1·5	2·2	4	0·7	1·3	0·7	1·1	0·8
(La/Ca) × 10^3	—	1·3	2·7	2·8	3·0	2·9	2·7	3·7	2·5	2·9	2·5	2·6	4·1	3·3	5·6	5·7	4·9	6·1	5·0	5·4	5·0	7·9	13	25	3·4	6·7	—	11·0	2·7
(Sr/Ca) × 10^3	7·8	12	17	23	12	16	16	13	16	21	16	17	18	28	27	30	32	34	37	27	35	27	4	5	17	24	33	20	12
(Ba/K) × 10^3	58	44	40	46	32	39	41	33	37	39	35	36	34	38	29	29	29	32	34	24	30	23	0·4	0·4	35	16	14	3	39
(Rb/K) × 10^3	7·5	6	12	7	7	7	5	7	4	6	7	4	8	6	5	5	5	5	5	6	6	8	7	5	6	5	5	4	8

TABLE 6. ROCK ANALYSES (* indicates new analysis)

Tristan

	ankaramites		olivine basalt	trachybasalts															
specimen no.	114*	62-1	6*	64-4	504*	64-3	364*	20*	21*	369*	622*	64-2	117*	347*	619*	351*	194*	125*	74-2
SiO_2	42·93	42·51	42·43	46·31	45·5	47·44	45·70	46·48	46·00	46·01	46·07	46·24	45·96	46·36	46·2	47·06	48·54	49·52	50·02
TiO_2	3·73	4·29	4·11	3·64	3·3	4·02	3·65	3·10	2·83	2·19	3·08	4·48	3·44	3·54	3·5	3·44	2·98	3·18	3·39
Al_2O_3	12·05	12·82	14·15	17·36	18·3	17·17	16·70	16·68	17·03	16·84	17·06	15·75	17·84	16·19	18·1	17·14	18·00	17·72	19·58
Fe_2O_3	5·58	4·89	5·84	3·27	2·5	3·10	3·73	4·12	3·79	7·61	2·59	3·04	4·53	3·66	3·1	3·29	3·78	2·55	2·29
FeO	8·27	8·64	8·48	8·12	8·4	7·07	7·28	7·30	7·47	5·37	8·32	7·39	6·21	6·94	6·7	6·65	5·18	5·66	5·24
MnO	0·16	0·13	0·17	0·17	0·1	0·14	0·17	0·18	0·23	0·18	0·18	0·14	0·20	0·18	0·2	0·18	0·18	0·18	0·12
MgO	10·28	9·63	6·71	4·64	4·6	4·65	4·89	4·65	4·80	4·75	4·72	4·92	4·13	4·57	4·6	4·35	3·32	3·42	3·15
CaO	12·58	12·22	11·91	9·74	10·0	9·78	9·91	9·40	9·54	9·36	9·35	9·57	9·61	9·45	9·4	9·00	8·49	7·58	6·32
Na_2O	2·36	2·83	2·77	3·67	4·2	3·71	3·96	3·80	4·04	3·74	4·01	4·12	4·27	3·97	4·7	4·08	4·74	4·94	5·15
K_2O	1·47	1·40	2·04	2·79	3·0	2·95	3·10	3·07	3·11	2·72	3·16	2·60	3·16	3·15	3·3	3·40	3·38	3·88	3·71
H_2O+	0·15	0·41	0·34	0·21	0·1	0·28	0·09	0·57	0·09	0·01	0·12	0·29	0·17	0·29	0·2	0·37	0·14	0·29	0·21
H_2O-	0·11	0·05	0·44	0·08	0·2	0·11	0·12	0·07	0·02	0·08	0·06	0·05	0·05	0·19	tr.	0·27	0·03	0·15	0·00
P_2O_5	0·59	0·38	0·58	0·00	0·3	0·00	0·84	0·90	1·06	1·18	1·22	1·20	0·52	1·42	0·5	0·75	1·18	1·09	1·02
Cl	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ZrO_2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	100·26	100·20	99·97	100·00	100·5	100·42	100·14	100·32	100·01	100·04	99·94	99·79	100·09	99·91	100·5	99·98	99·94	100·16	100·20
analyst	J.R.B.		J.R.B.		I.D.B.		J.R.B.	M.H.K.	M.H.K.	M.H.K.	M.H.K.		J.R.B.	J.R.B.	I.D.B.	J.R.B.	M.H.K.	J.R.B.	
NORMS																			
Q	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Z	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
or	8·68	8·28	12·06	16·49	17·73	17·74	18·32	18·15	18·38	16·08	18·68	15·37	18·68	18·62	19·51	20·10	19·98	22·93	21·93
ab	6·73	5·58	6·95	11·94	6·03	14·24	11·58	16·16	13·27	21·63	13·63	19·82	11·88	17·92	8·70	15·45	22·80	22·48	28·06
an	17·95	18·15	20·16	22·66	22·23	21·49	18·64	19·39	19·15	21·13	19·22	16·81	20·18	17·06	18·55	18·42	17·86	14·72	19·36
leu	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ne	7·17	9·95	8·93	10·36	15·99	9·29	11·88	8·66	11·33	5·43	10·99	8·15	13·13	8·49	16·83	10·33	9·37	10·46	8·40
di	32·18	31·76	28·01	20·85	20·80	21·69	20·12	17·25	17·24	13·73	15·71	18·28	19·16	16·51	19·95	17·15	13·15	12·68	4·26
ol	10·76	9·92	5·48	5·77	6·84	3·76	5·11	6·12	7·21	4·03	9·09	5·33	2·53	5·51	4·47	4·85	2·73	4·17	5·86
hy	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
wo	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
mt	8·09	7·09	8·47	4·74	3·63	4·49	5·41	5·97	5·49	11·03	3·76	4·41	6·57	5·31	4·49	4·77	5·48	3·70	3·32
il	7·08	8·15	7·81	6·91	6·27	7·63	6·93	5·89	5·37	4·16	5·85	8·51	6·53	6·72	6·65	6·53	5·65	6·04	6·44
hm	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ap	1·39	0·90	1·37	—	0·71	—	1·98	2·12	2·50	2·78	2·88	2·81	1·23	3·35	1·18	1·77	2·78	2·51	2·41
fr	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
hl	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
H_2O+	0·13	0·39	0·32	0·21	0·09	0·28	0·05	0·53	0·05	0·04	0·07	0·24	0·15	0·23	0·18	0·34	0·09	0·24	0·17
H_2O-	0·11	0·05	0·44	0·08	0·20	0·11	0·12	0·07	0·02	0·08	0·06	0·05	0·05	0·19	—	0·27	0·03	0·15	—
pf	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ru	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
tn	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	100·27	100·22	100·00	100·01	100·52	100·42	100·14	100·31	100·01	100·04	99·94	99·80	100·09	99·92	100·52	99·98	99·92	100·15	100·21
$\frac{FeO}{MgO+FeO}$% in *di, ol, hy*	12·3	13·7	16·3	30·0	35·0	21·0	22·2	25·5	28·8	1·8	35·2	19·6	14·8	22·0	22·4	22·6	14·2	23·1	18·6
differentiation index	22·6	23·8	27·9	38·8	39·7	41·0	41·8	43·0	43·0	43·1	43·3	43·3	43·7	45·0	45·0	45·9	52·2	55·9	58·4

Tristan (continued)

	trachyandesites									trachytes				
specimen no.	230*	232*	80-1	657*	518*	617*	572*	627*	80-5	560*	86-3	30*	31*	86-5
SiO_2	53·90	54·04	54·43	54·95	54·53	54·76	54·1	54·66	54·35	58·0	58·20	59·6	60·7	58·71
TiO_2	1·77	1·81	1·82	1·58	1·62	1·62	1·7	1·60	2·18	1·2	1·33	0·5	0·5	0·39
Al_2O_3	19·00	19·54	18·23	19·63	19·35	19·06	20·0	19·91	19·97	19·5	19·10	19·6	20·5	20·03
Fe_2O_3	3·37	2·60	3·24	1·62	4·85	3·15	2·0	3·07	1·52	1·7	2·24	2·4	2·3	2·16
FeO	3·05	3·35	2·66	3·31	1·20	2·95	3·3	2·73	3·15	2·2	1·28	0·1	0·4	0·45
MnO	0·18	0·19	0·09	0·18	0·18	0·18	0·2	0·18	0·24	0·1	0·08	0·2	0·2	0·10
MgO	1·68	1·66	1·52	1·42	1·50	1·51	1·8	1·10	1·35	1·0	0·81	0·4	0·2	0·00
CaO	6·25	6·22	5·83	5·73	5·76	5·60	5·2	5·56	4·52	3·3	3·58	1·3	1·4	0·98
Na_2O	5·04	5·26	5·64	5·89	5·84	5·87	6·1	5·85	6·71	6·5	6·30	5·7	6·2	7·56
K_2O	4·53	4·53	4·71	4·95	4·83	4·89	5·6	5·03	4·53	5·3	5·94	6·6	6·7	6·03
H_2O+	0·19	0·11	1·55	0·00	0·00	0·03	0·2	0·00	0·38	0·2	0·90	2·3	1·0	3·19
H_2O-	0·28	0·19	0·00	0·01	0·02	0·03	0·3	0·00	0·04	0·1	0·13	1·3	0·4	0·22
P_2O_5	0·74	0·75	0·42	0·43	0·38	0·36	0·3	0·29	0·89	0·2	0·21	0·05	0·03	0·06
Cl	—	—	—	0·27	0·11	0·13	—	0·23	—	—	0·06	—	—	0·32
F	—	—	—	0·08	0·12	0·10	—	0·10	—	—	—	—	—	—
ZrO_2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	99·98	100·25	100·14	99·96†	100·22†	100·17†	100·8	100·22†	99·83	99·3	100·16	100·05	100·53	100·13
analyst	J.R.B.	J.R.B.		M.H.K.	M.H.K.	M.H.K.	I.D.B.	M.H.K.		I.D.B.		I.D.B.	I.D.B.	
NORMS														
Q	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C	—	—	—	—	—	—	—	—	—	—	—	0·84	0·58	—
Z	—	—	—	—	—	—	—	—	—	—	—	—	—	—
or	26·78	26·78	27·84	29·27	28·55	28·88	33·10	29·72	26·78	31·33	35·11	39·01	39·60	35·64
ab	33·37	32·25	33·33	29·99	31·61	31·67	22·20	31·14	35·16	40·12	37·51	44·39	43·57	42·87
an	15·85	16·33	10·52	13·57	12·68	11·74	10·66	14·10	11·00	8·38	6·53	6·12	6·75	4·17
leu	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ne	5·02	6·64	7·80	9·66	9·26	9·23	15·94	9·03	11·71	8·06	8·32	2·08	4·82	10·15
di	8·09	7·71	8·17	9·60	8·03	8·96	10·64	6·22	4·52	5·36	4·35	—	—	—
ol	0·45	1·30	—	0·94	—	—	0·96	—	1·85	0·55	—	0·70	0·35	—
hy	—	—	—	—	—	—	—	—	—	—	—	—	—	—
wo	—	—	2·16	—	0·88	0·77	—	1·29	—	—	1·78	—	—	0·12
mt	4·89	3·77	3·59	2·34	—	4·56	2·90	4·45	2·20	2·46	0·53	—	0·49	0·65
il	3·36	3·44	3·46	3·00	2·91	3·08	3·23	3·03	4·14	2·28	2·53	0·64	0·95	0·74
hm	—	—	0·76	—	4·85	—	—	—	—	—	1·87	2·40	1·96	1·71
ap	1·75	1·77	0·99	1·01	0·91	0·84	0·71	0·67	2·10	0·47	0·50	0·12	0·07	0·14
fr	—	—	—	0·09	0·17	0·14	—	0·16	—	—	—	—	—	—
hl	—	—	—	0·45	0·18	0·21	—	0·37	—	—	0·10	—	—	0·53
H_2O+	0·16	0·08	1·53	0·02	0·02	0·03	0·19	0·00	0·34	0·19	—	2·30	1·00	3·19
H_2O-	0·28	0·19	—	—	0·02	0·03	0·30	0·00	0·04	0·10	—	1·30	0·40	0·22
pf	—	—	—	—	0·12	—	—	—	—	—	—	—	—	—
ru	—	—	—	—	—	—	—	—	—	—	—	0·16	—	—
tn	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	100·00	100·25	100·15	99·93	100·17	100·14	100·83	100·18	99·84	99·30	100·13	100·06	100·54	100·13
$\frac{FeO}{MgO+FeO}$% in *di, ol, hy*	4·0	20·1	0	34·7	0	8·8	25·1	4·5	23·7	20·4	0	0	0	100
differentiation index	65·2	65·7	69·0	70·1	70·4	70·7	71·2	71·5	73·6	79·5	80·9	85·5	88·0	88·7

† Corrected for O = F, Cl.

Nightingale

	trachybasalts					trachyandesites			trachytes			
specimen no.	1713-4	401*	74-1	74-3	74-4	80-4	80-6	412*	420*	86-1	439*	86-4
SiO_2	48·09	48·59	48·76	50·64	52·13	54·40	57·10	57·31	58·07	59·91	62·50	62·23
TiO_2	4·38	2·61	2·93	2·50	2·00	2·38	1·11	1·59	1·25	1·21	0·38	0·65
Al_2O_3	19·05	17·78	15·10	21·75	20·48	17·34	21·05	17·01	18·01	18·44	20·39	18·43
Fe_2O_3	3·44	2·64	4·23	0·19	3·81	3·04	1·76	6·47	2·92	2·88	0·31	1·68
FeO	5·59	5·12	5·27	5·93	2·20	3·69	2·01	0·28	2·30	1·20	0·84	0·60
MnO	0·00	0·17	0·07	0·07	0·07	0·07	0·11	0·12	0·13	0·07	0·09	0·12
MgO	3·50	3·53	3·54	2·56	1·96	2·50	1·20	2·05	1·15	0·97	0·02	0·11
CaO	9·42	8·08	7·45	6·88	5·55	4·94	4·13	3·71	3·15	2·73	1·28	1·16
Na_2O	5·06	4·13	4·43	5·27	3·92	5·11	5·01	5·38	6·00	6·05	5·93	6·77
K_2O	2·88	3·27	3·96	3·73	3·75	4·73	5·33	5·17	6·02	5·83	7·08	6·28
H_2O+	0·67	1·86	3·11	0·44	2·21	1·11	0·97	0·10	0·28	0·30	0·64	1·60
H_2O-	0·00	1·30	0·43	0·31	1·96	0·00	0·43	0·28	0·38	0·16	0·69	0·06
P_2O_5	0·00	0·87	0·83	0·00	0·00	0·69	0·00	0·52	0·43	0·22	0·10	0·07
Cl	—	—	—	—	—	—	—	—	—	—	—	0·32
F	—	—	—	—	—	—	—	—	—	—	—	—
ZrO_2	—	—	—	—	—	0·10	—	—	—	—	—	—
	102·08	99·95	100·11	100·27	100·04	100·10	100·21	99·99	100·09	99·97	100·25	100·01
analyst		M.H.K.						M.H.K.	M.H.K.		M.H.K.	
NORMS												
Q	—	—	—	—	0·23	—	—	—	—	—	—	—
C	—	—	—	—	—	—	—	—	—	—	0·89	—
Z	—	—	—	—	—	0·15	—	—	—	—	—	—
or	17·02	19·33	23·41	22·05	22·16	27·96	31·50	30·55	35·58	34·46	41·85	37·12
ab	16·09	24·79	23·52	19·59	33·17	36·58	37·61	45·52	39·17	44·90	46·34	51·79
an	20·77	20·32	9·63	24·68	27·22	10·41	19·21	7·00	4·44	5·95	5·70	2·61
leu	—	—	—	—	—	—	—	—	—	—	—	—
ne	14·48	5·50	7·56	13·54	—	3·61	2·59	—	6·28	3·41	2·08	1·69
di	19·16	11·31	17·34	7·84	0·25	7·52	1·01	3·13	6·18	4·80	—	0·59
ol	—	4·74	1·49	6·80	—	2·24	2·22	2·56	—	0·14	0·67	—
hy	—	—	—	—	4·77	—	—	—	—	—	—	—
wo	0·59	—	—	—	—	—	—	—	0·19	—	—	0·80
mt	5·00	3·83	6·13	0·28	1·52	4·41	2·55	—	4·21	0·59	0·44	0·44
il	8·32	4·96	5·56	4·75	3·80	4·52	2·11	0·85	2·37	2·30	0·72	1·23
hm	—	—	—	—	2·76	—	—	6·47	0·01	2·47	—	1·38
ap	—	2·05	1·96	—	—	1·63	—	1·23	1·01	0·52	0·24	0·17
fr	—	—	—	—	—	—	—	—	—	—	—	—
hl	—	—	—	—	—	—	—	—	—	—	—	0·53
H_2O+	0·67	1·82	3·08	0·44	2·21	1·08	0·97	0·08	0·26	0·29	0·64	1·60
H_2O-	—	1·30	0·43	0·31	1·96	—	0·43	1·28	0·38	0·16	0·69	0·06
pf	—	—	—	—	—	—	—	1·11	—	—	—	—
ru	—	—	—	—	—	—	—	—	—	—	—	—
tn	—	—	—	—	—	—	—	1·21	—	—	—	—
	102·10	99·95	100·12	100·28	100·05	100·11	100·20	99·99	100·08	99·99	100·26	100·01
$\frac{FeO}{MgO+FeO}$% in *di, ol, hy*	1·6	21·8	11·3	44·6	0	5·4	13·4	0	0	0	92·7	0
differentiation index	47·6	49·6	54·5	55·2	55·6	68·1	71·7	76·1	81·0	82·8	90·3	90·6

Inaccessible

	olivine basalt	trachybasalts					trachyandesites		trachyte
specimen no.	88-1	466*	64-1	70-3	70-1	70-2	80-2	80-3	86-2
SiO_2	48·11	46·4	47·76	49·30	49·30	48·10	55·51	54·94	62·36
TiO_2	3·27	2·6	3·05	3·18	2·02	2·60	2·12	2·18	0·72
Al_2O_3	14·29	17·7	15·68	16·36	18·85	19·39	18·20	17·69	18·99
Fe_2O_3	2·01	3·3	3·34	3·69	4·37	8·02	3·04	2·97	1·76
FeO	7·63	7·2	6·55	5·94	5·80	3·03	4·03	3·29	0·87
MnO	0·15	0·2	0·07	0·16	tr.	0·13	0·13	0·12	0·04
MgO	10·13	5·8	6·05	5·31	3·95	2·01	2·05	2·87	0·78
CaO	9·71	9·3	9·02	7·40	7·66	4·61	4·67	4·73	1·78
Na_2O	2·92	3·9	4·22	4·09	3·89	4·81	5·43	5·05	6·30
K_2O	0·98	2·6	1·94	1·71	2·65	2·56	3·15	3·76	5·01
H_2O+	0·46	0·8	1·87	1·67	0·45	1·87	0·56	1·03	0·63
H_2O-	0·09	0·9	0·00	0·49	0·30	2·08	0·25	0·47	0·24
P_2O_5	0·31	0·2	0·49	0·49	0·64	0·00	0·56	0·62	0·21
Cl	—	—	—	—	—	—	—	—	—
F	—	—	—	—	—	—	—	—	—
ZrO_2	—	—	—	—	—	—	—	—	—
	100·06	100·9	100·04	99·79	99·88	100·11	99·70	99·72	99·69
analyst		I.D.B.							
NORMS									
Q	—	—	—	—	—	—	0·40	—	2·16
C	—	—	—	—	—	0·33	—	—	0·47
Z	—	—	—	—	—	—	—	—	—
or	5·79	15·37	11·47	10·11	15·66	15·13	18·62	22·22	29·61
ab	24·71	13·19	24·51	34·61	30·65	36·93	45·94	42·73	53·30
an	23·00	23·12	18·11	21·24	26·65	22·87	15·99	14·50	7·46
leu	—	—	—	—	—	—	—	—	—
ne	—	10·73	6·07	—	1·23	2·04	—	—	—
di	18·49	17·54	18·72	9·76	6·16	—	2·82	3·84	—
ol	15·05	9·07	7·52	5·23	7·62	5·08	—	1·24	—
hy	2·63	—	—	4·18	—	—	5·39	3·81	1·94
wo	—	—	—	—	—	—	—	—	—
mt	2·91	4·78	4·84	5·35	6·34	2·65	4·41	4·31	0·85
il	6·21	4·94	5·79	6·04	3·84	4·94	4·03	4·14	1·37
hm	—	—	—	—	—	6·19	—	—	1·18
ap	0·73	0·47	1·16	1·16	1·51	—	1·32	1·46	0·50
fr	—	—	—	—	—	—	—	—	—
hl	—	—	—	—	—	—	—	—	—
H_2O+	0·45	0·79	1·85	1·65	0·42	1·87	0·54	1·00	0·62
H_2O-	0·09	0·90	—	0·49	0·32	2·08	0·25	0·47	0·24
pf	—	—	—	—	—	—	—	—	—
ru	—	—	—	—	—	—	—	—	—
tn	—	—	—	—	—	—	—	—	—
	100·06	100·9	100·04	99·82	99·88	100·11	99·71	99·73	99·70
$\frac{FeO}{MgO+FeO}$% in *di, ol, hy*	17·9	25·7	18·1	14·3	22·3	0	19·5	2·2	0
differentiation index	30·5	39·3	42·0	44·7	47·5	54·1	65·0	65·0	85·1

FIGURE 20. The 1961 Eruptive Centre from the top of the Main Cliffs.

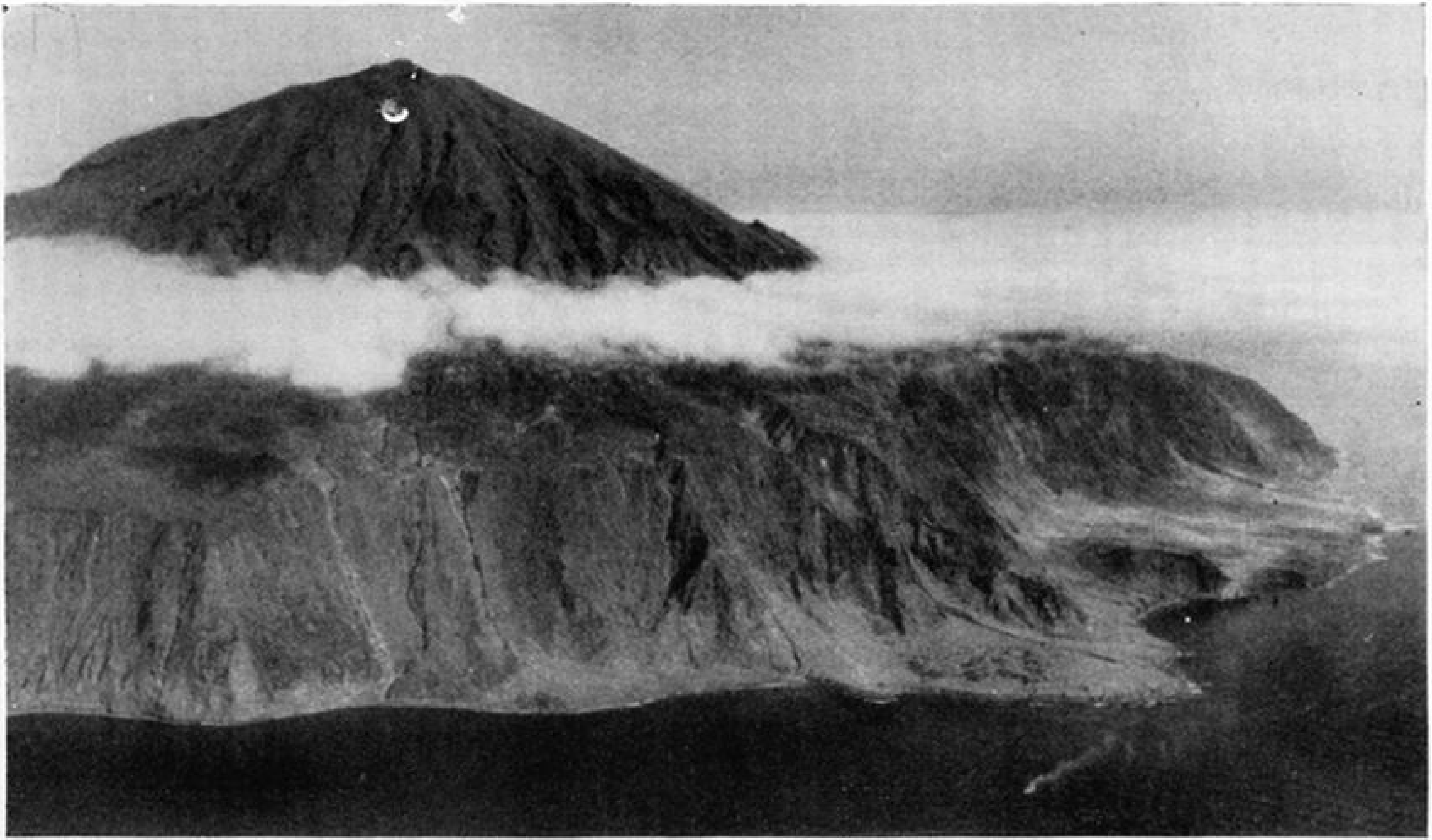


FIGURE 21. The north side of Tristan: taken from H.M.S. *Protector*'s helicopter in 1960 before the eruption. The typical volcanic form of the island is well illustrated, as is the Settlement coastal plain.

FIGURE 22. A view westwards along the northern coast of Tristan illustrating the steepness of the Main Cliffs and their sharp contact with the Base.

FIGURE 23. The Peak from the west (Burntwood): this view emphasizes the difference in slope of the Peak and the Base.

FIGURE 24. The south side of Tristan from Queen Mary's Peak: the gradual decrease in gradient away from the summit is illustrated. The parasitic cinder cones of Stony Beach Hills and Cave Gulch Hill are prominent at the edge of the Base.

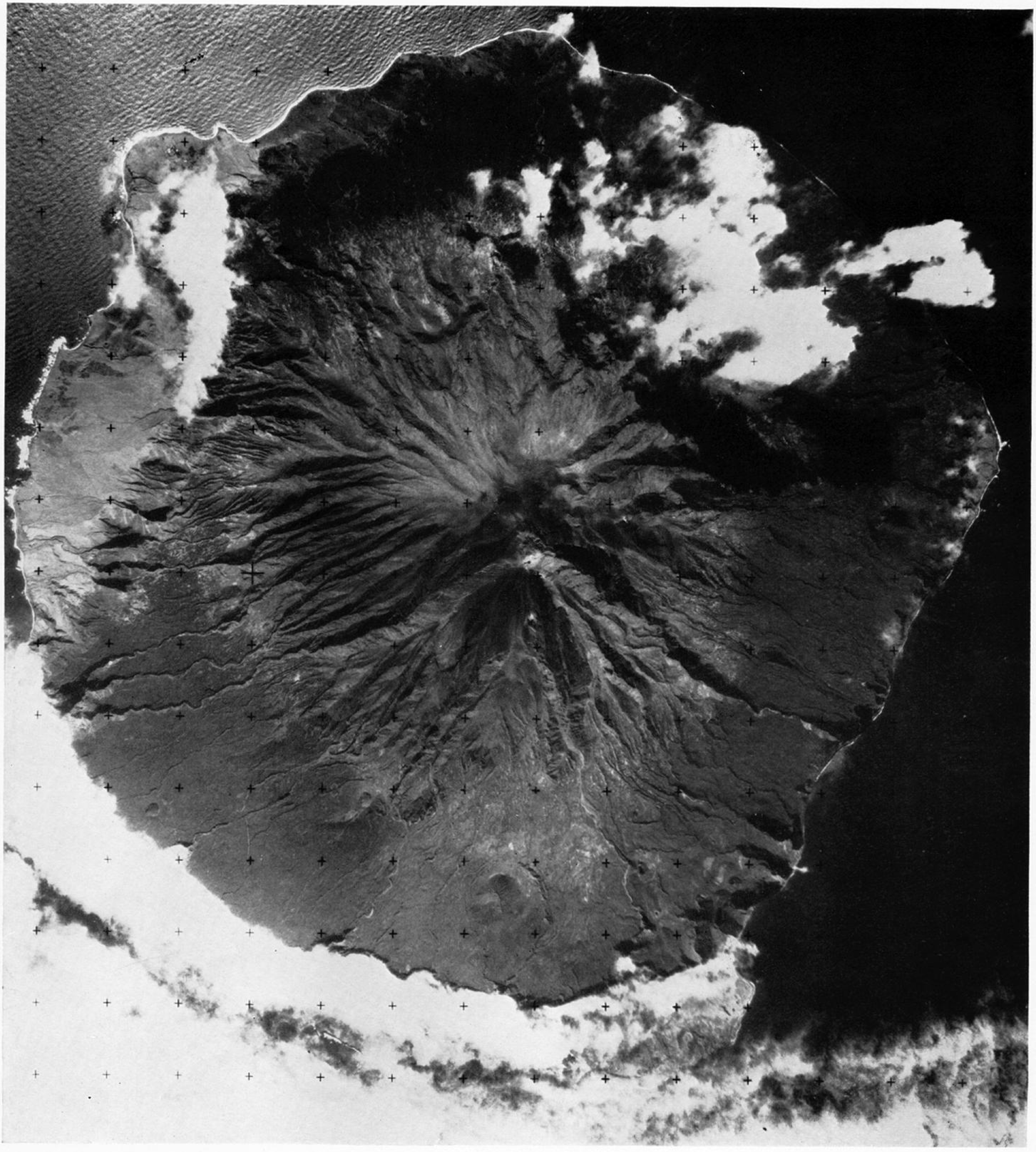


Figure 25

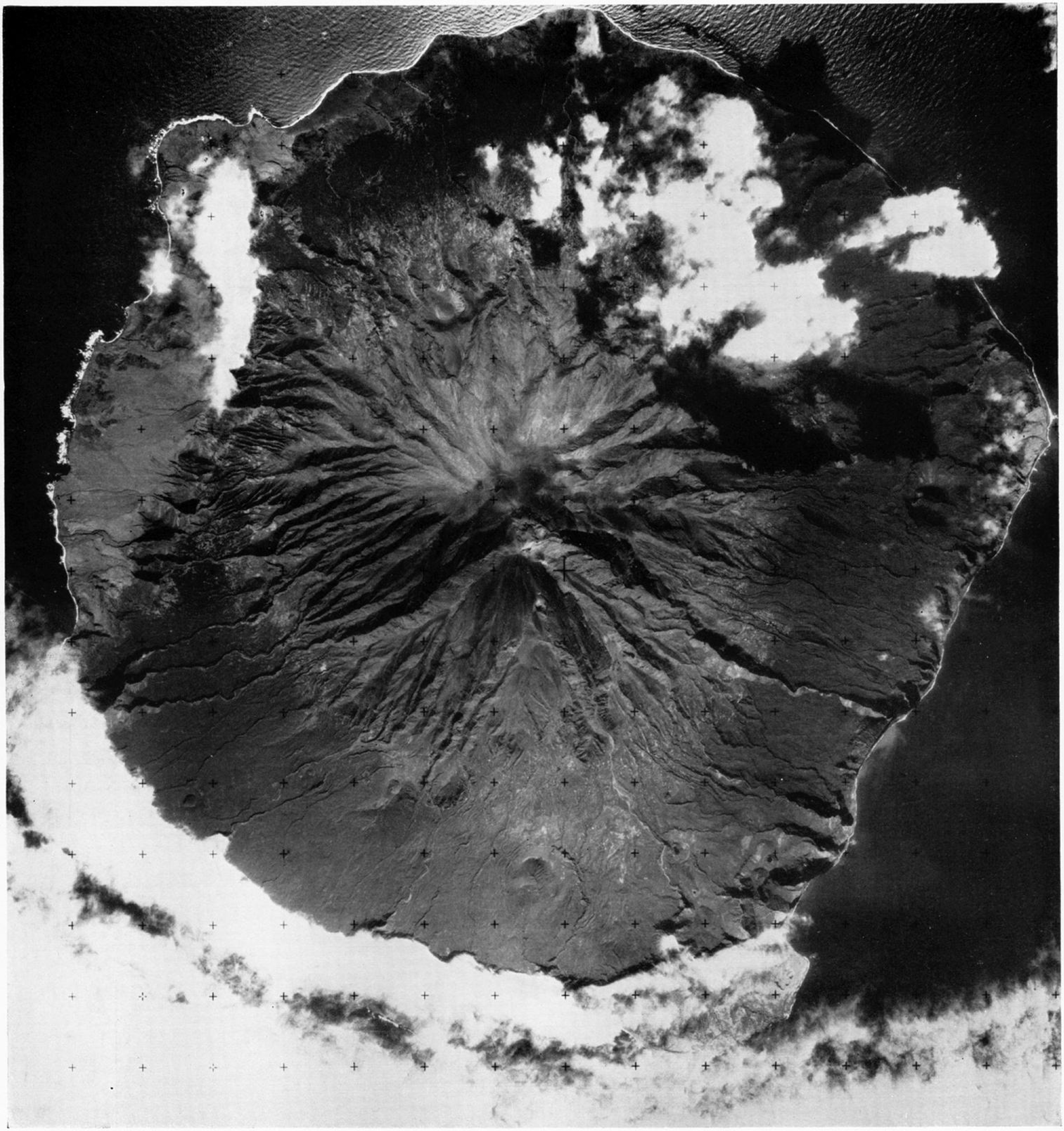


Figure 26

Figures 25 and 26. Stereopair of aerial photographs of Tristan taken by the Royal Air Force on 3 April 1961 from 42 000 ft. To be examined with a mirror stereoscope.

FIGURE 27. Main Cliffs near Pigbite; trachybasalt lavas of the main sequence with interbedded fragmental horizons which are the rubbly tops and bottoms of the adjacent flows.

FIGURE 28. East end of Sandy Point Gulch; Sandy Point parasitic centre, a parasitic complex within the main sequence showing thick flow-banded trachybasalt lavas flowing over red basaltic agglomerate.

FIGURE 29. The summit crater lake.

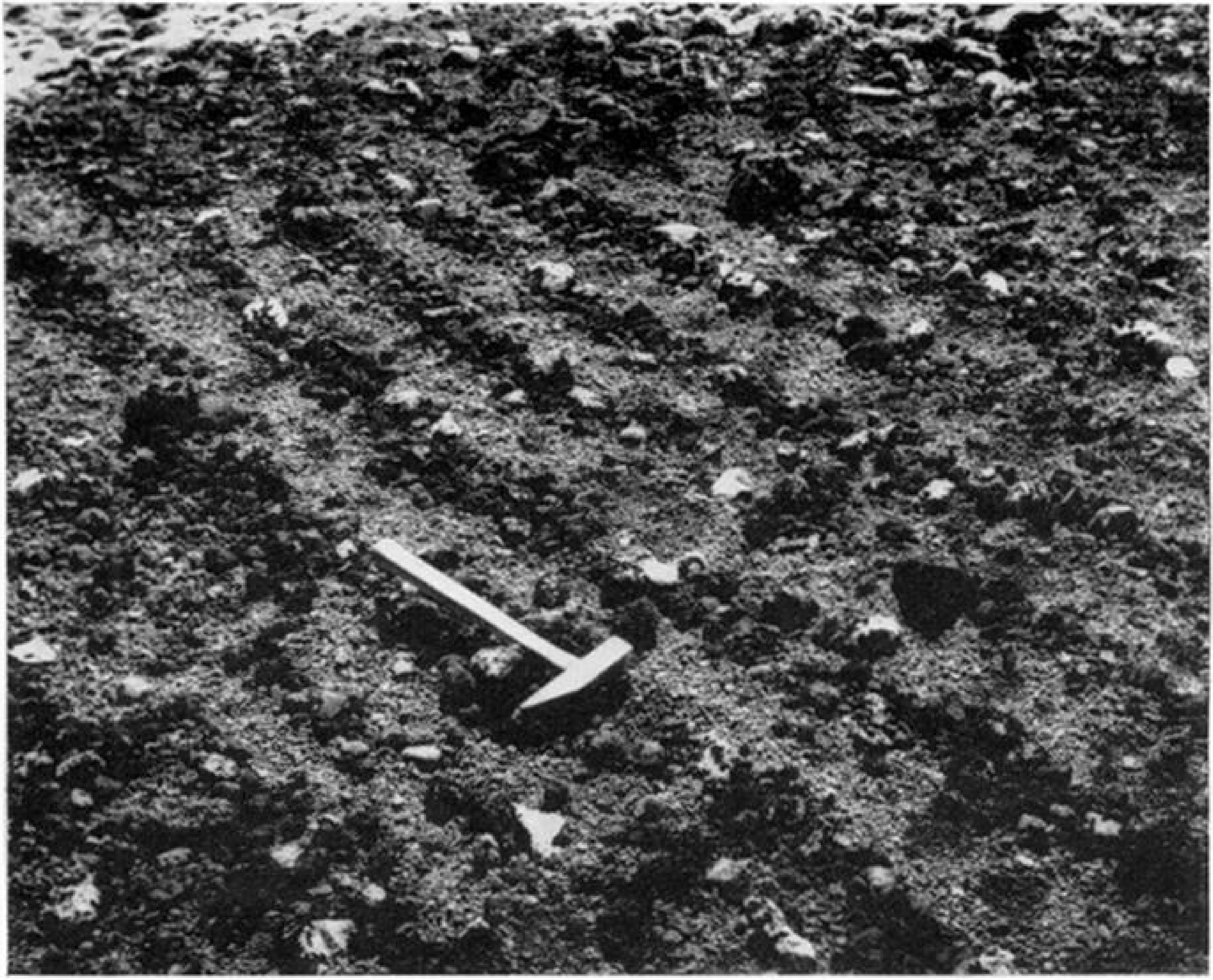


FIGURE 30. Rock stripes: solifluxion phenomena on the rim of the summit crater.

FIGURE 31. Trachybasalt dyke exposed in Main Cliffs, Big Point.

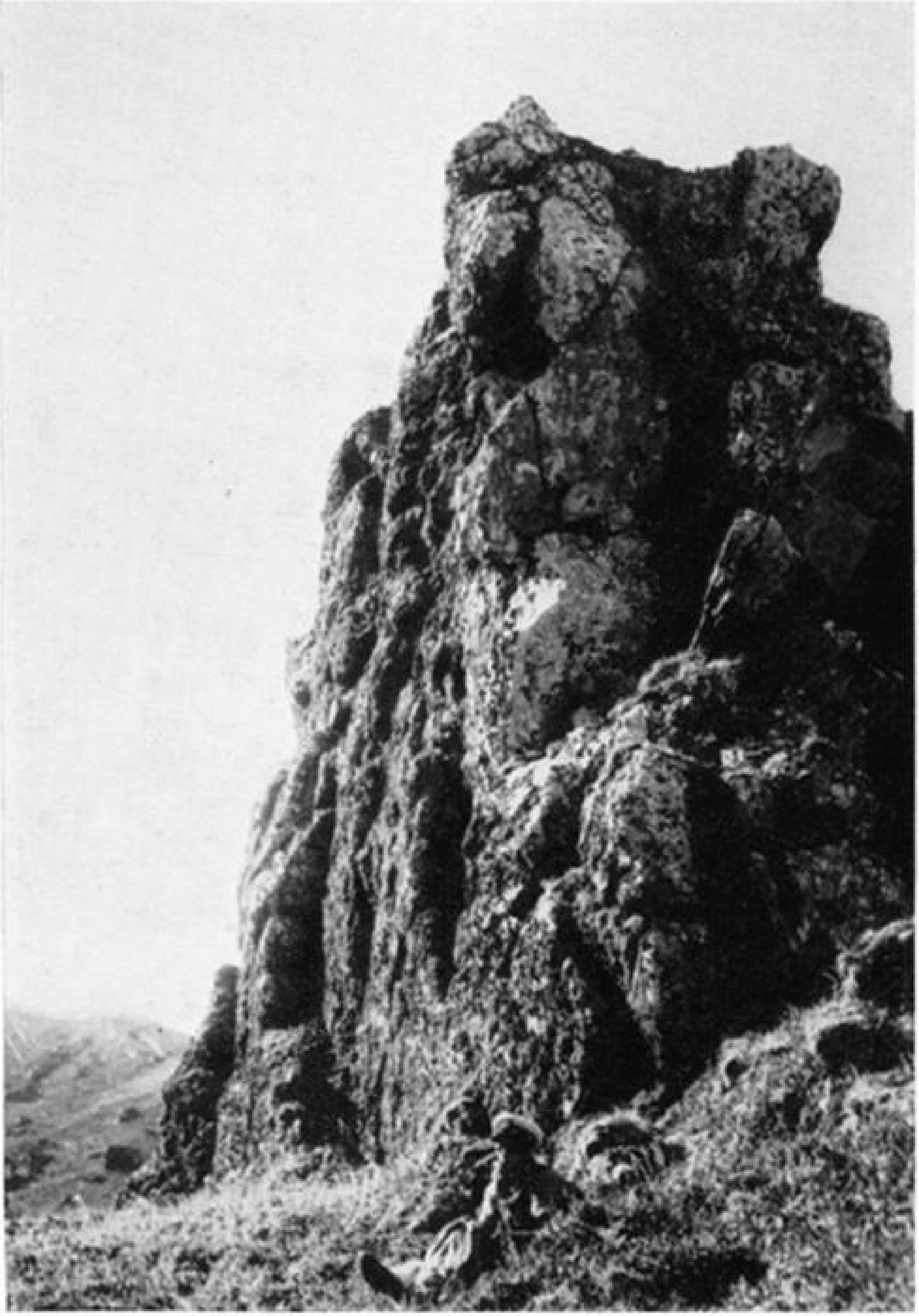


FIGURE 32. Wall dyke near the summit; upper reaches of Deep Gulch. 5750 ft. O.D.

FIGURE 33. Top Pond from its southern rim: showing the V-shaped outlet on the north side. This outlet is not an erosional feature but is due to crater overlap.

FIGURE 34. Bottom Pond from the southern rim: showing pebble beach and exposure of tuff and agglomerate in the northern crater wall.

FIGURE 35. Big Green Hill from the south: a typical cinder cone now almost completely vegetated. A carbonaceous layer underlies the cinder cone and is exposed where Pigbite Gulch dissects the western flank. Radiocarbon dating indicates an age of 10770 ± 156 B.P. for the carbonaceous layer indicating an age of about 10000 years for the cinder cone.

FIGURE 36. Nellie's Hump from the north-east: an old parasitic scoria mound whose form has been considerably modified by erosion. Typical badland gullying on the north-east flank reveals volcanic agglomerate.

FIGURE 37. The Hillpiece parasitic complex from the east showing Burnthill in the foreground. Photograph taken from half-way up the Main Cliffs.

FIGURE 38. Hillpiece from the sea.

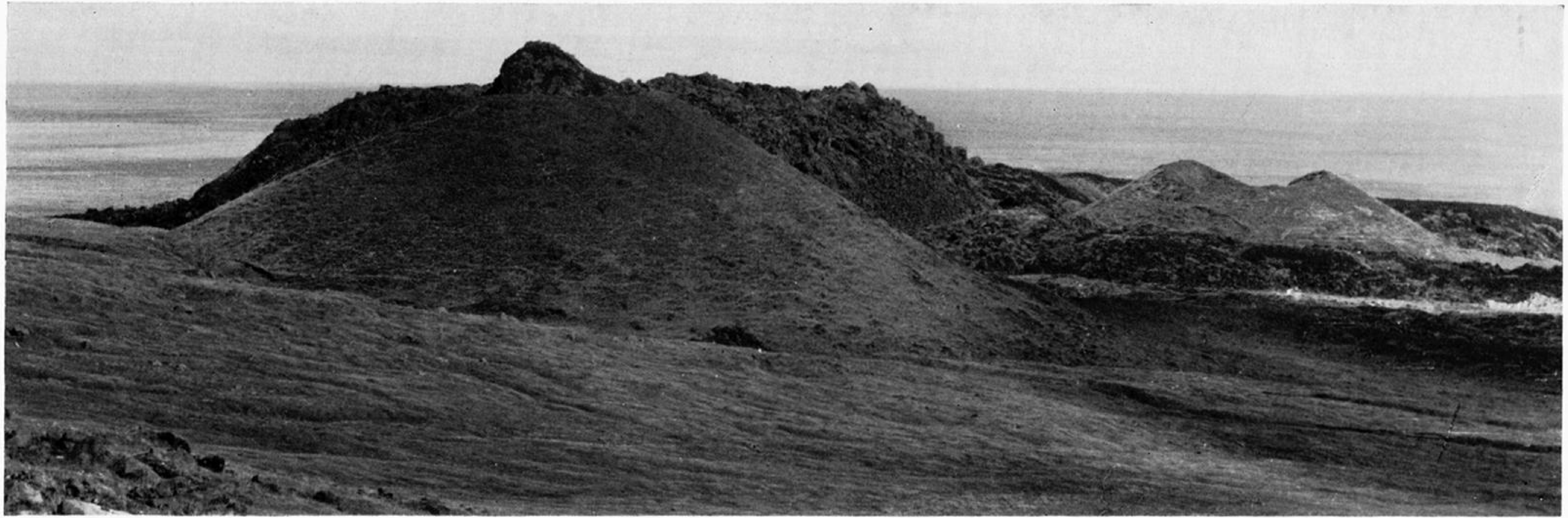


FIGURE 39. The Stony Hill Group from the north-west: Hill-with-a-hole-in is in the foreground partly obscuring Stony Hill. Kipuka Hill is to the right of Stony Hill.

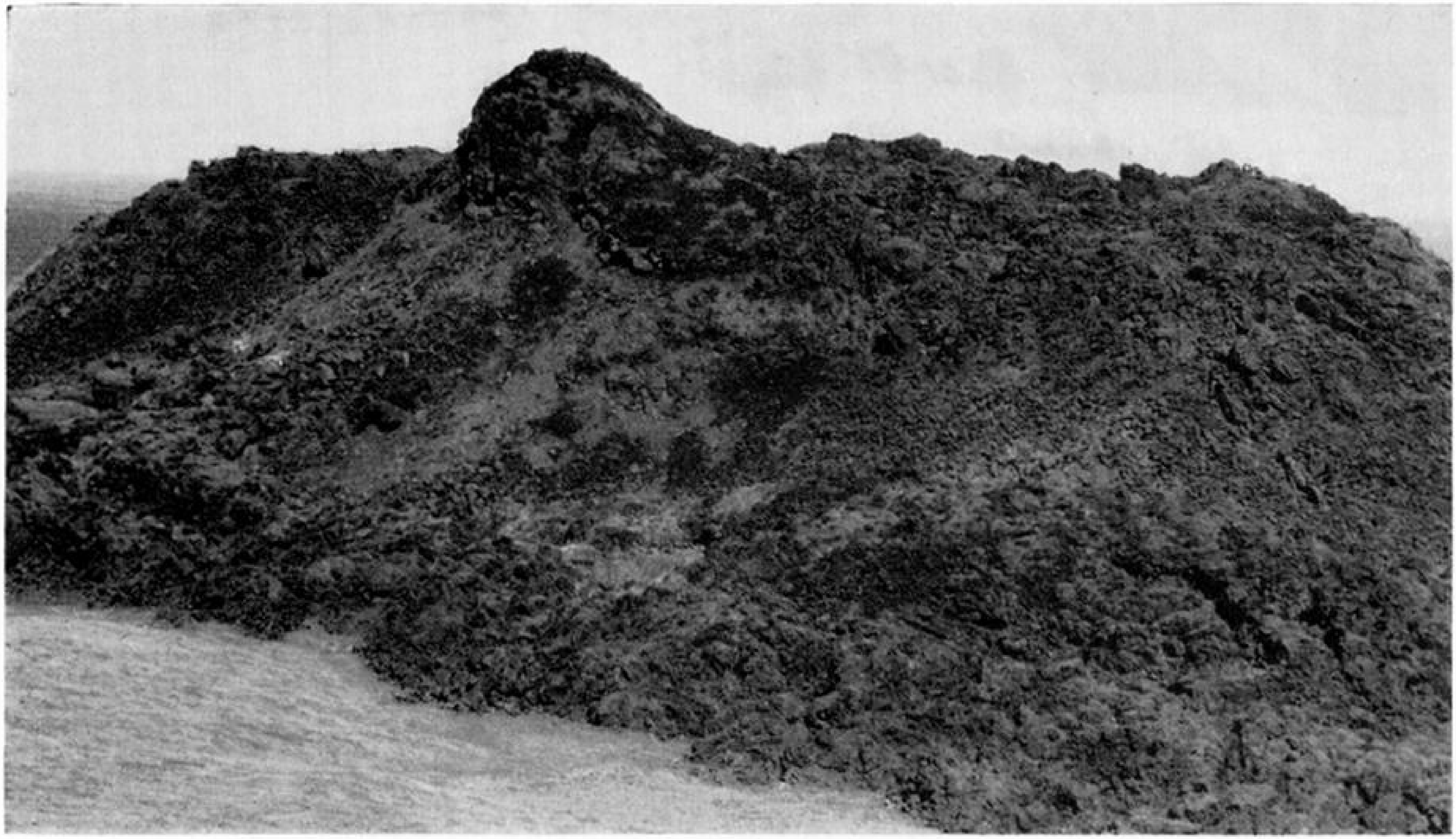


FIGURE 40. Stony Hill from the summit of the Hill-with-a-hole-in.

FIGURE 41. Hill-with-a-hole-in from the south-west showing the narrow lava flow that issued from the base of the cinder cone.

FIGURE 42. The Settlement Plain south of Hillpiece from the Base at Burntwood.

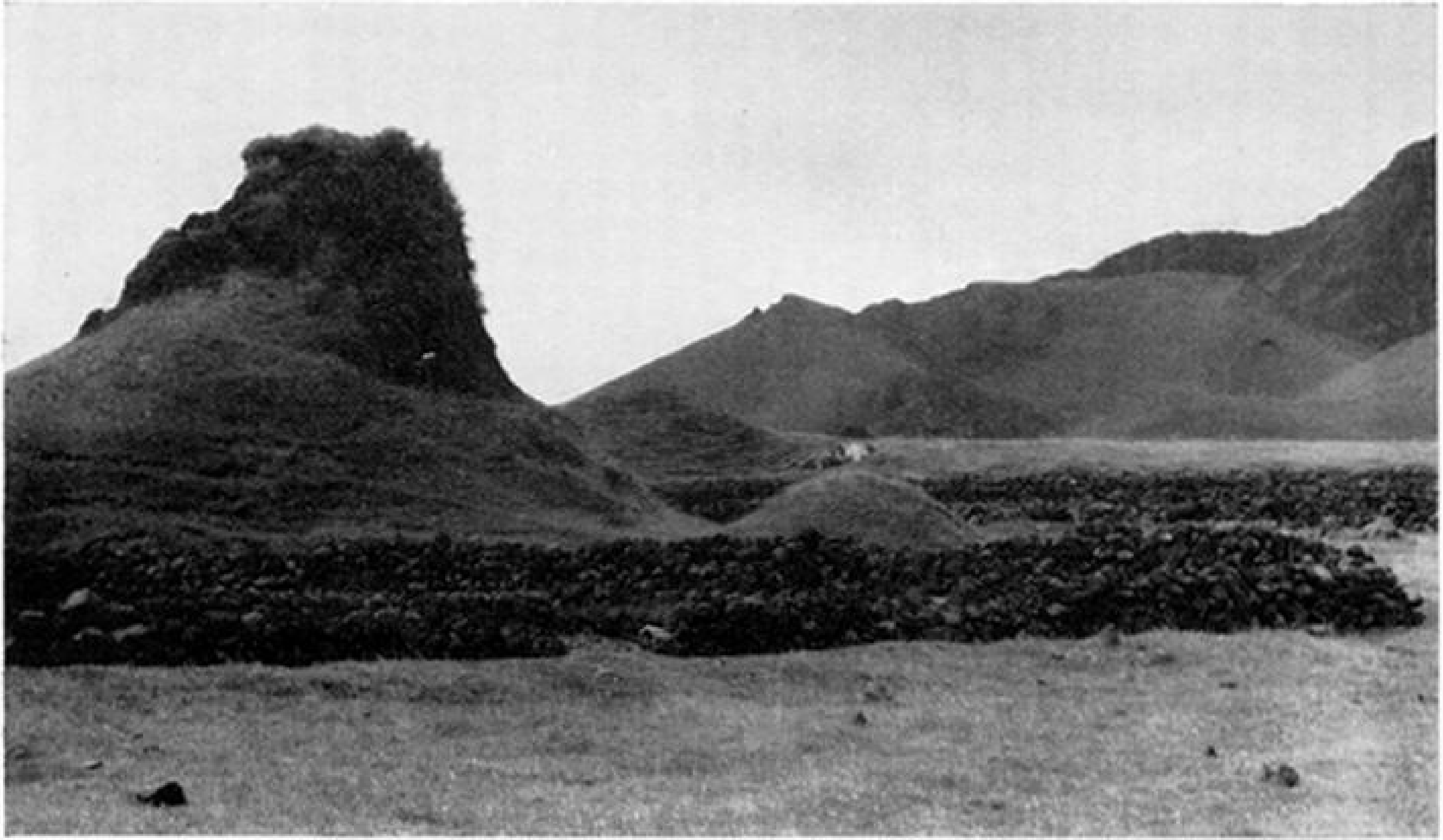


FIGURE 43. Hornitos on the Settlement Plain south of Hillpiece in the vicinity of the potato patches.

FIGURE 44. Entrail lavas on the foreshore north of the Settlement and immediately west of the 1961 lava.

FIGURE 45. Seal Bay Plateau from the top of the Main Cliffs.

FIGURE 46. Sandy Point: the eastern extremity of Tristan.

FIGURE 47. The Nightingale Group from the north: note the absence of any volcanic landscape form.

FIGURE 48. Middle and Stoltenhoff Islands from the vicinity of the 'Molly' Ponds on Nightingale.

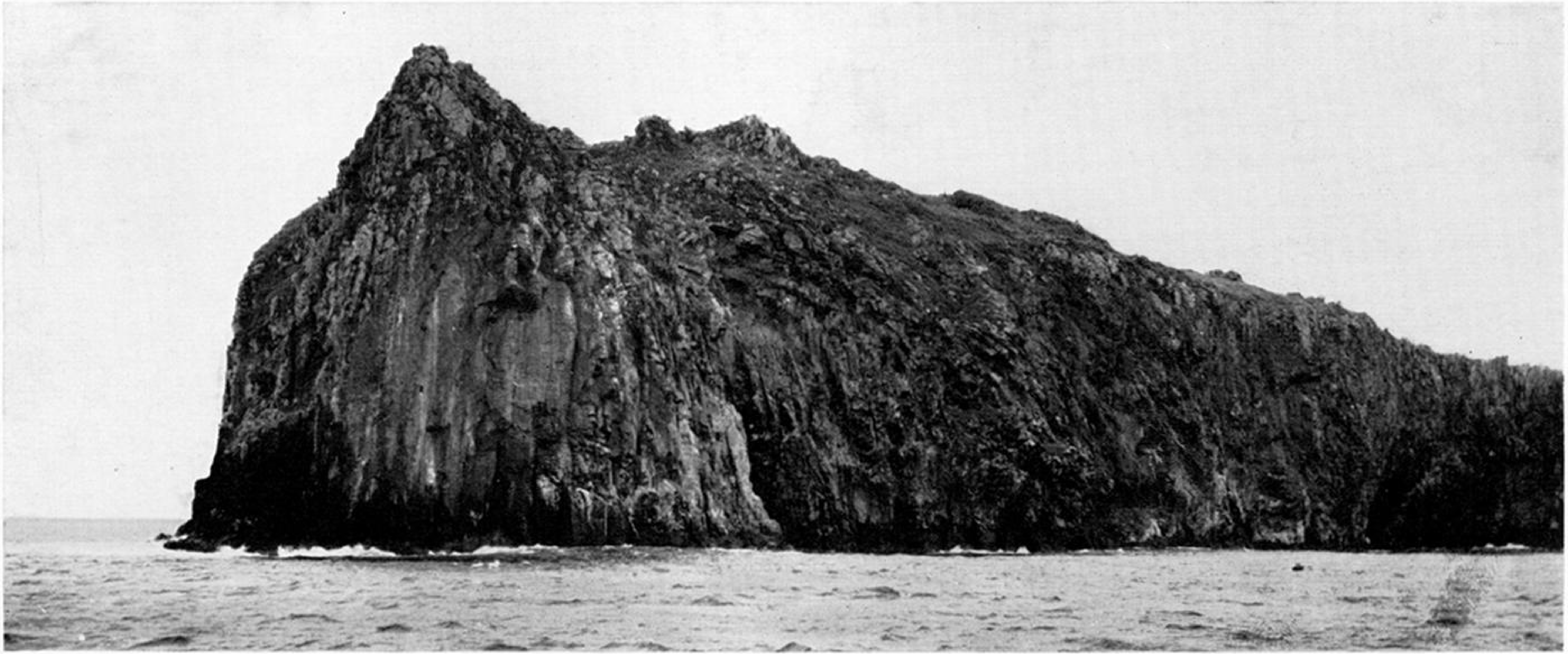


FIGURE 49. The south-western end of Stoltenhoff Island: Stoltenhoff is a monolithic mass of biotite trachyte, columnar jointed in places.

FIGURE 50. High Ridge: the ridge of high ground forming the eastern part of Nightingale Island seems to be a monolithic mass of trachyte.

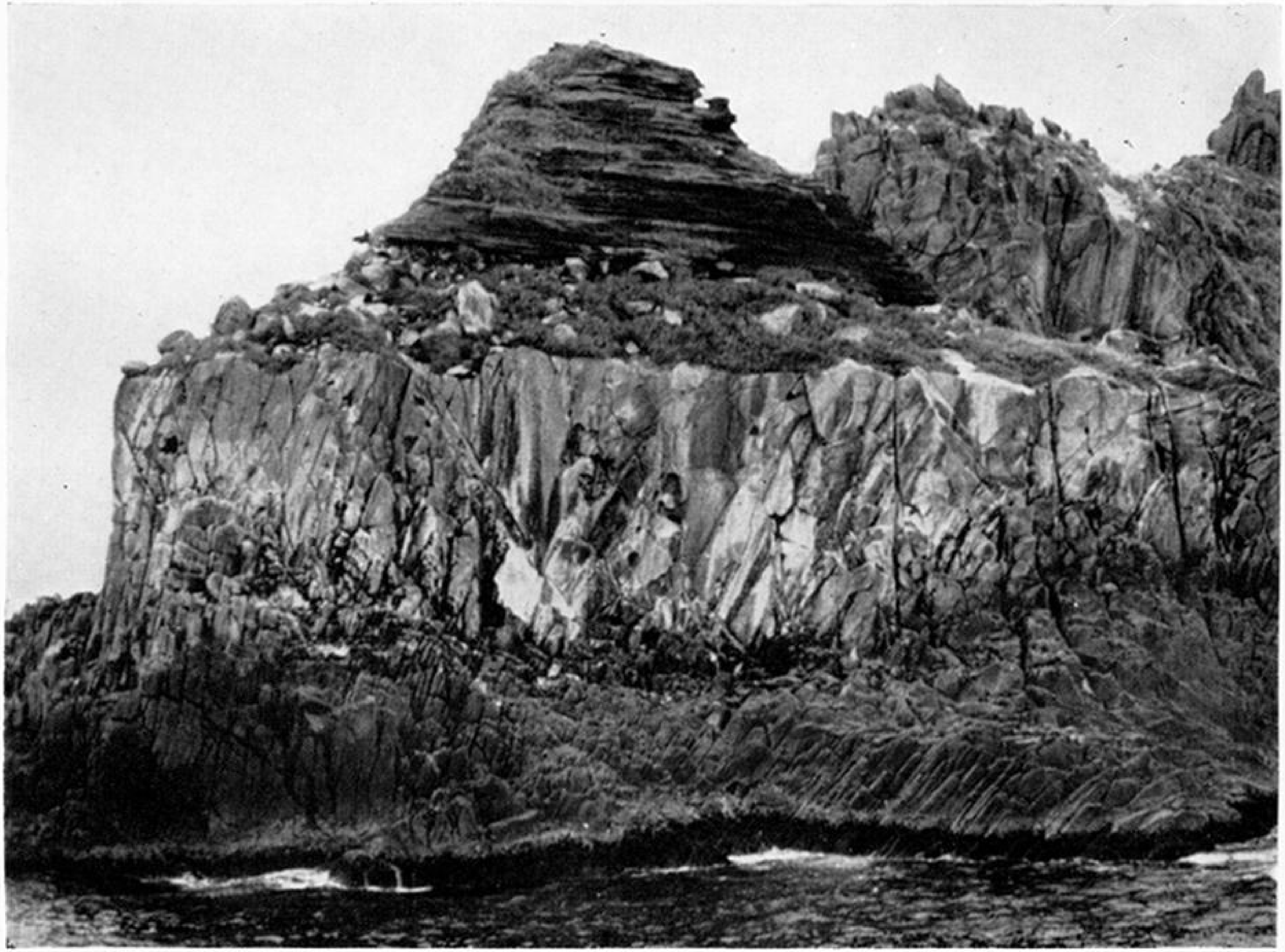


FIGURE 51. The hardie off Sea hen Rocks: these rocks are formed of trachyte overlain in part by buff coloured tuff. Between the trachyte and the tuff is a carbonaceous layer (covered by grass in photograph) dated as $39160 \begin{smallmatrix} +6090 \\ -3410 \end{smallmatrix}$ years B.P. by radiocarbon methods.

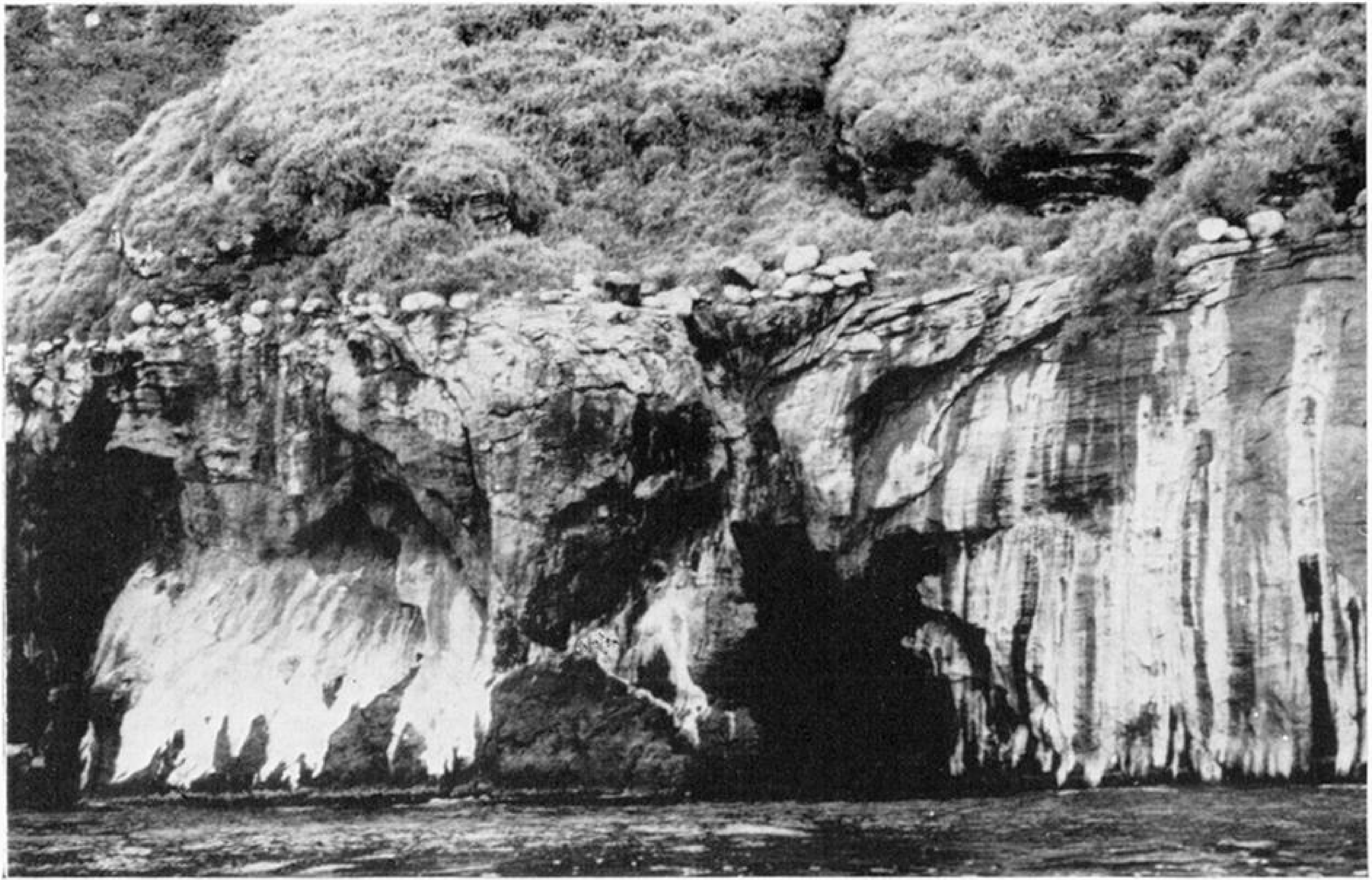


FIGURE 52. The sea cliffs on the eastern side of Petrel Bay. The boulder bed is about 60 ft. above sea-level and separates the underlying, older pyroclastic sequence from the finer grained pyroclastics of the younger sequence.

FIGURE 53. The 'Molly' Ponds: North Pond from the east.

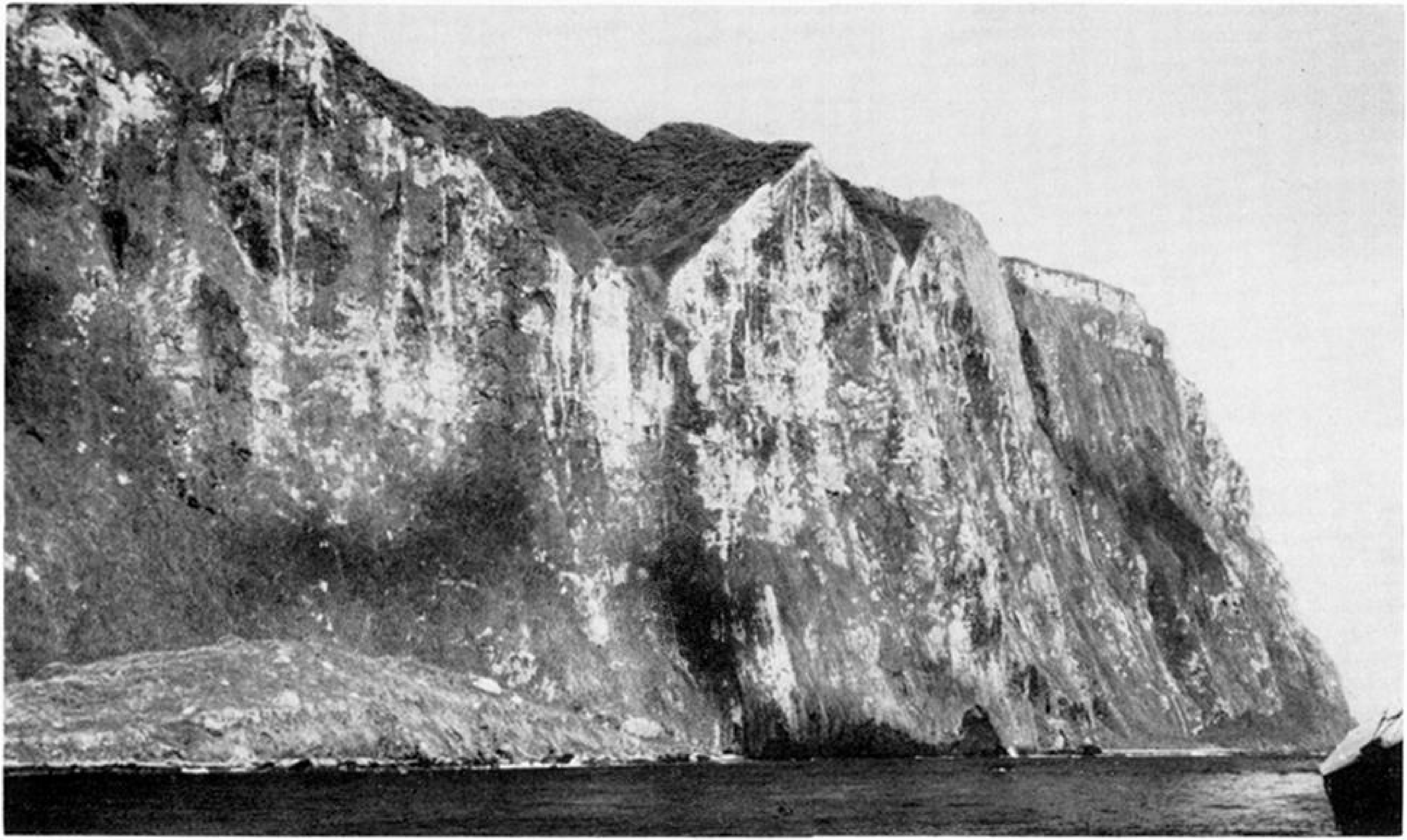


FIGURE 54. South-east coast: vertical white lines are dykes. Note the gentle eastern inclination of the lavas of the main sequence.

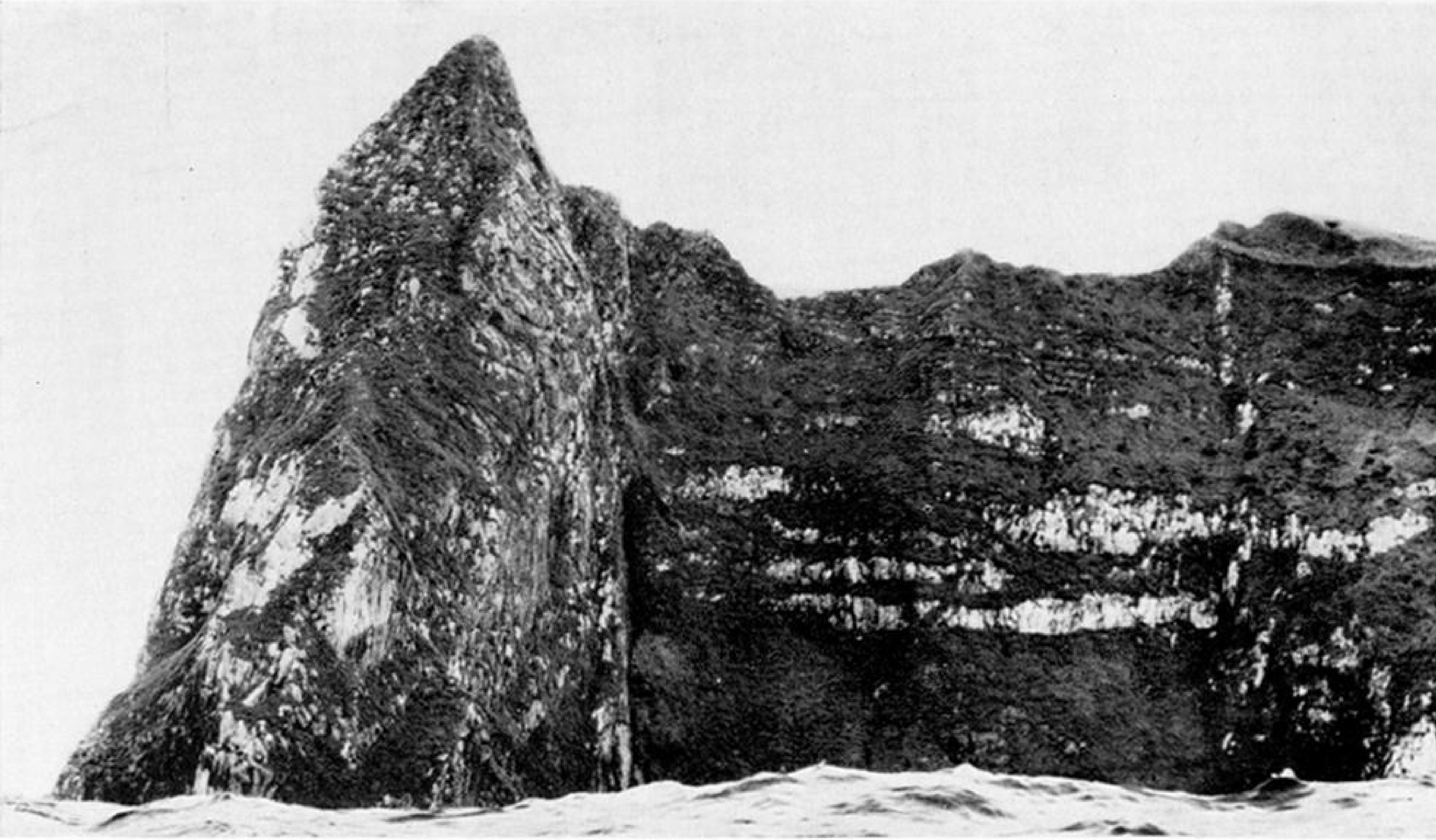


FIGURE 55. South Point: a trachyte dome displaying marked columnar jointing in places; a similar dome, Pyramid Rock, occurs nearby.

FIGURE 56. The Blenden Hall dome: a trachyte dome in the base of the cliff section behind the low promontory of Blenden Hall; the smooth surface is due to exfoliation weathering and is in contrast with the rugged outline of South Point.

FIGURE 57. The waterfall, Salt Beach: clearly visible in the cliff section is a parasitic centre in which thin basaltic flows are interleaved with pyroclastic debris. Part of a surface cinder cone can be seen outlined against the sky.

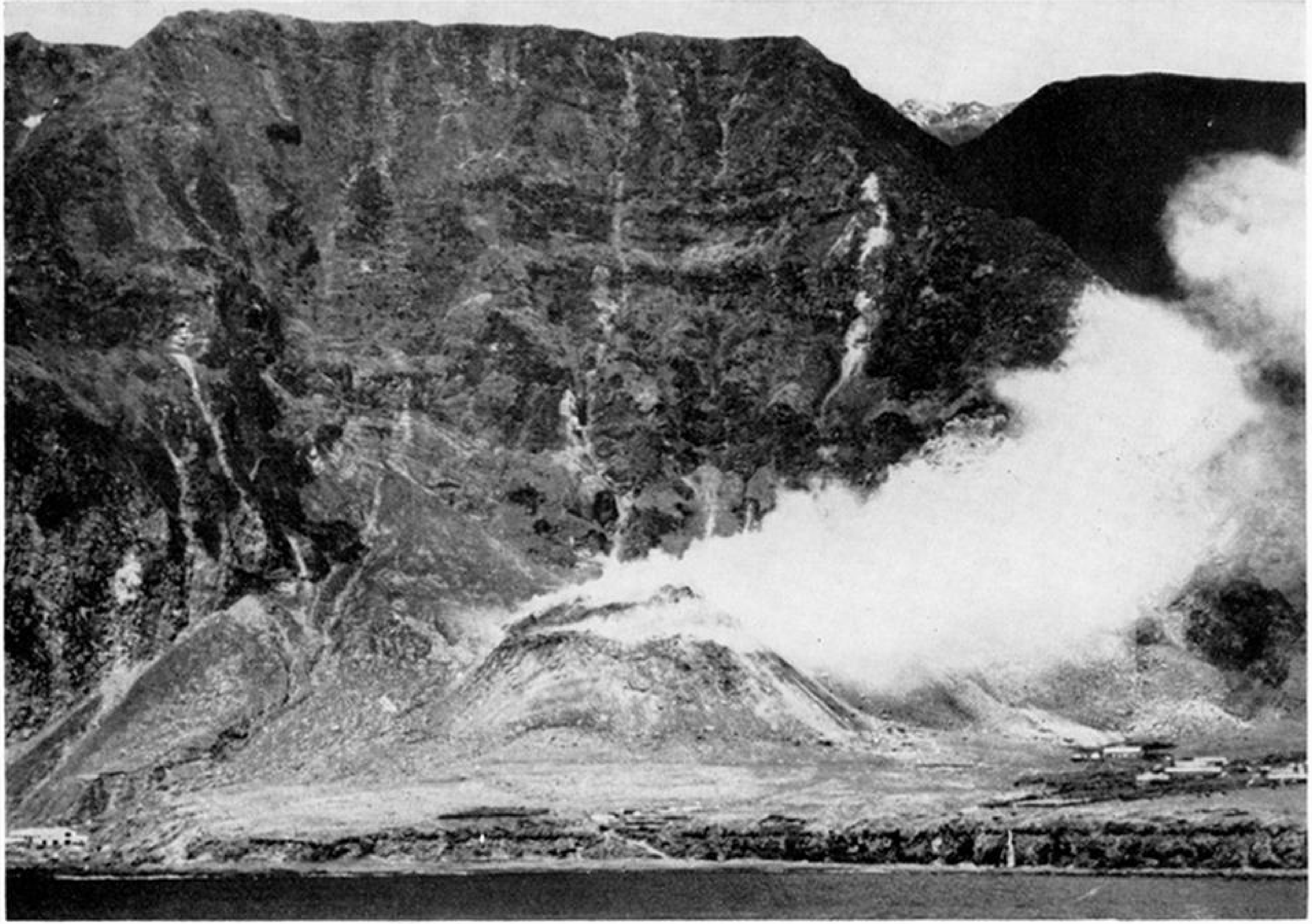


FIGURE 58. 12 October 1961. The initial tholoid from H.M.S. *Leopard*. Official photograph, Crown Copyright reserved.

FIGURE 59. 14 October 1961. The initial tholoid from the village. Official photograph, Crown Copyright reserved.

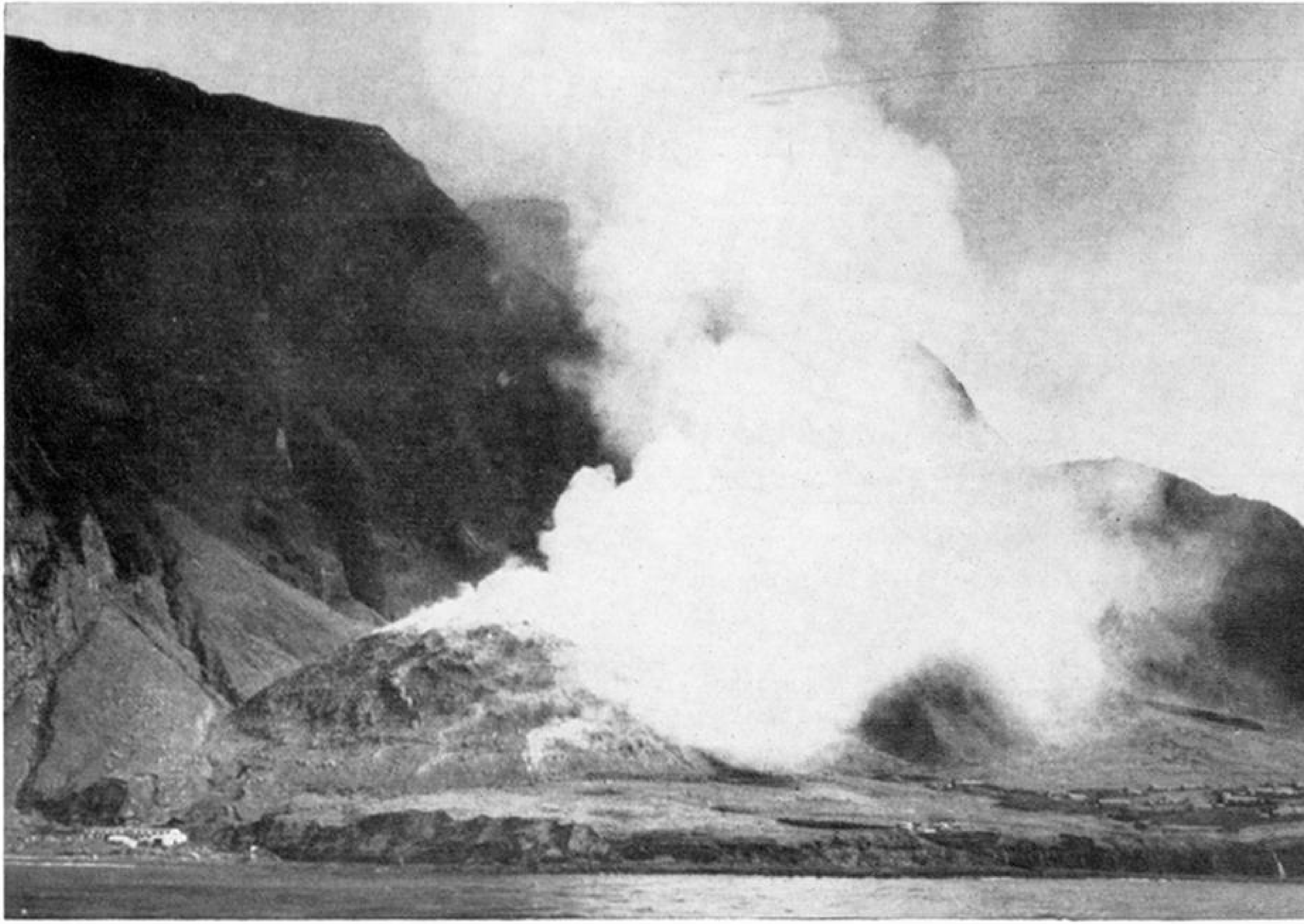


FIGURE 60. 21 October 1961. The tholoid, now nearly 400 ft. high; considerable growth had taken place during the preceding week. Photograph by Captain M. T. Scott, M.V. *Tristania*.

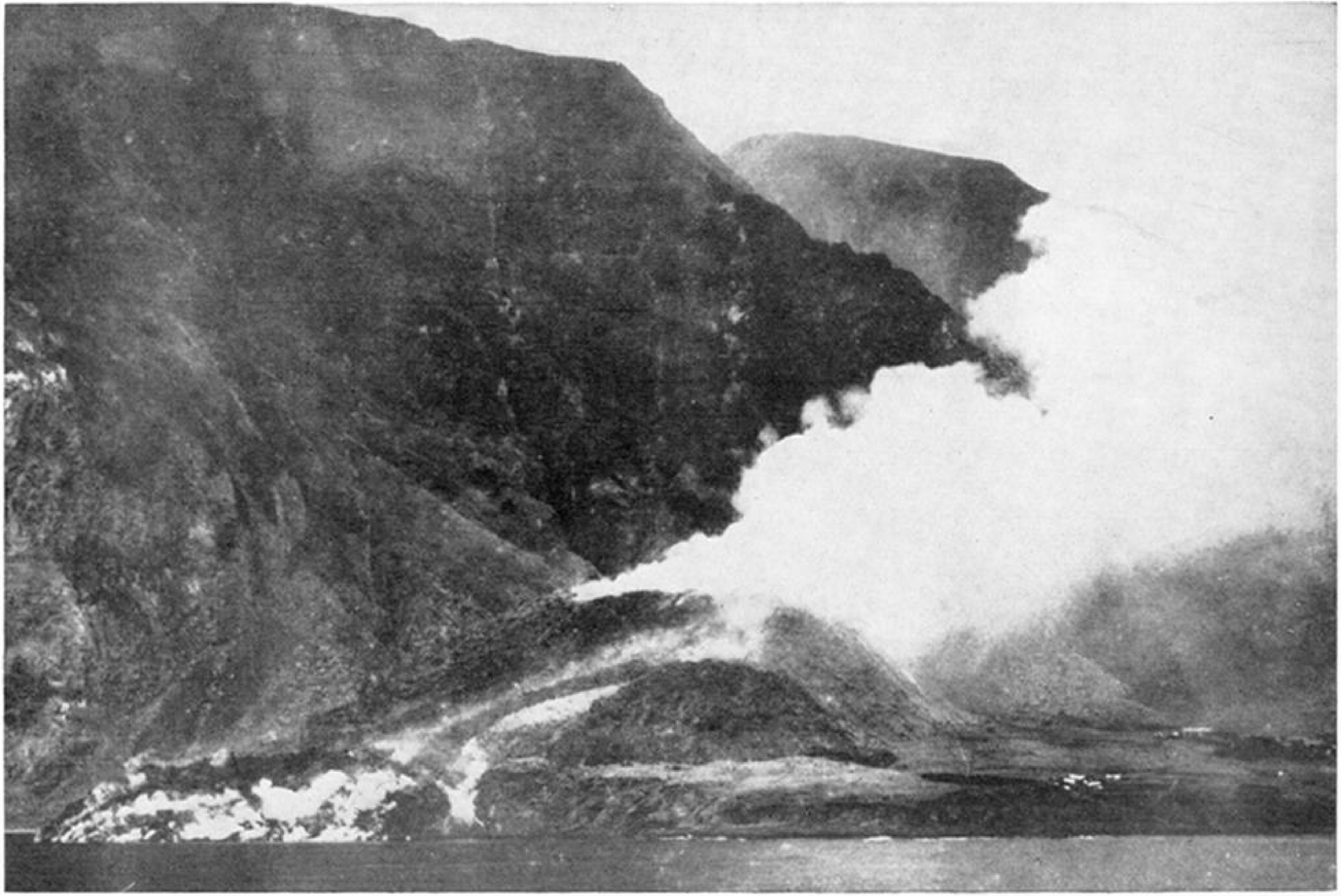


FIGURE 61. 27 October 1961. The tholoid had breached on the seaward side and the lava extended for 100 yards into the sea having engulfed the craw-fish canning factory. Photograph by Captain M. T. Scott, M.V. *Tristania*.

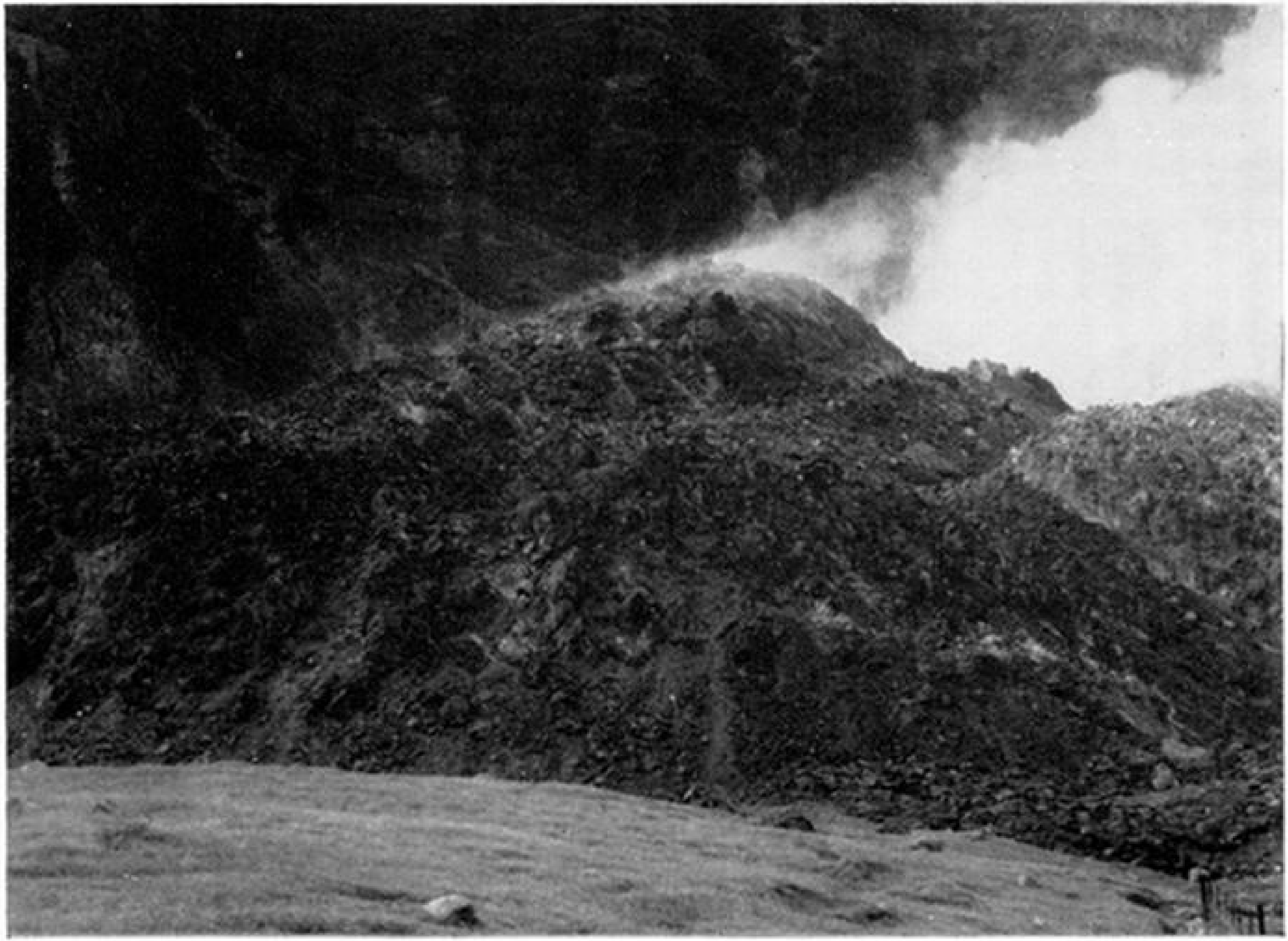


FIGURE 62. The source region from the west: showing the outer wall of the tholoid, the depression of the fosse and the elongated form of the dome. Late February 1962.

FIGURE 63. The western side of the central cone from the fosse. The pinnacles are of reddish blocky lava and less conspicuous scoria. This vent was the source area for all the effusive products of the eruption.

Figure 64. The dome in the early stages of development (early February 1962) from the lava field.

FIGURE 65. The western flank of the dome showing the walls that 'peeled off' during the period of maximum growth. Sharp dentate plications cover the surface of the dome and the wall.

FIGURE 66. The surface of the central flow from the flow dome.

FIGURE 67. The boulder beach or bar formed in four weeks during late February and early March. The bar extends from the eastern margin of the new lava field eastwards to Pigbite and encloses a small lagoon. By September 1962 a similar bar, 200 yards long, had been built up at the western end of the new lava field.

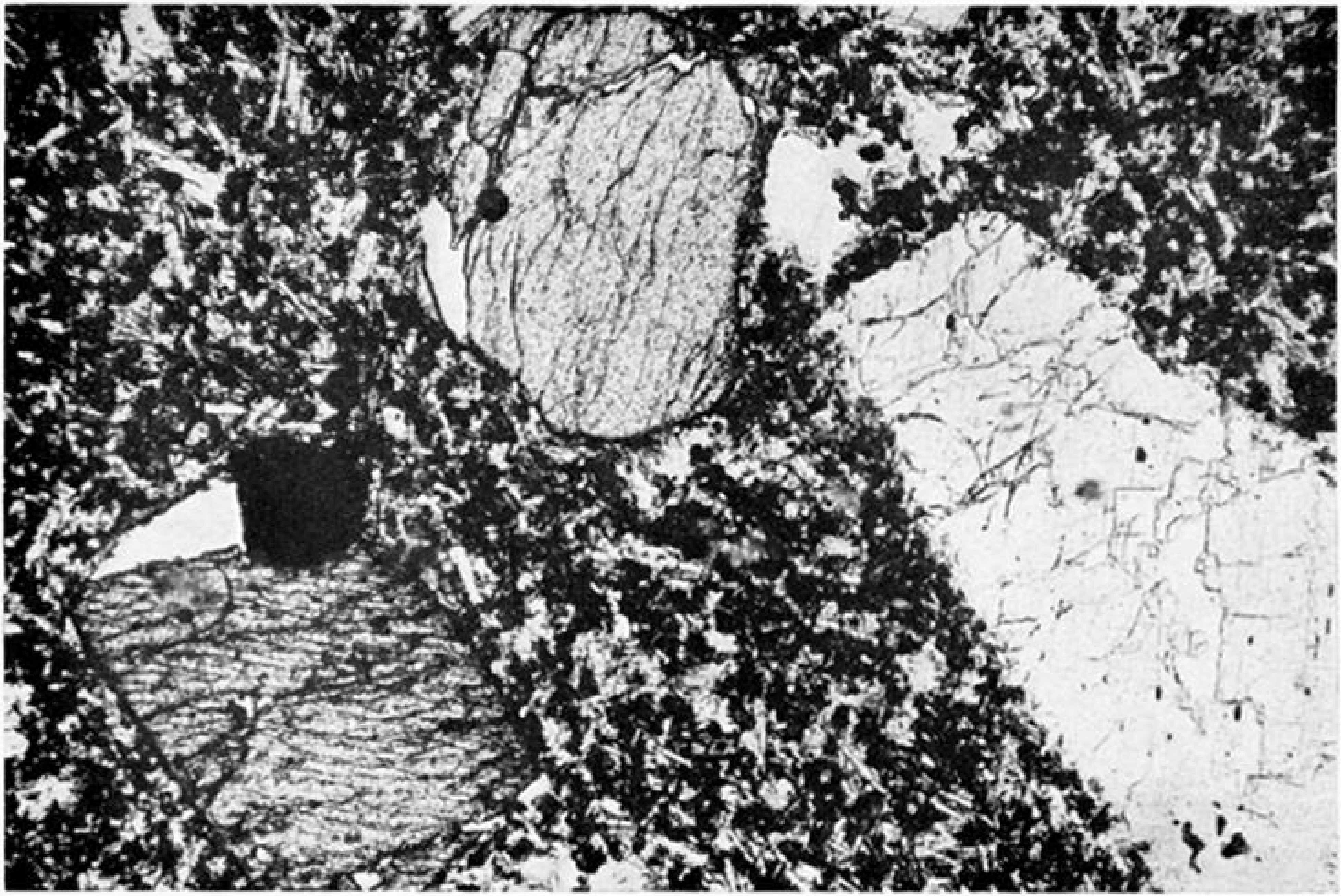


FIGURE 68. *Ankaramite* (114). Base of Main Cliffs east end of Sandy Point. Phenocrysts of olivine, pyroxene and plagioclase set in a groundmass of pyroxene, plagioclase and iron ore. Plane polarized light. (Magn. ×34.)

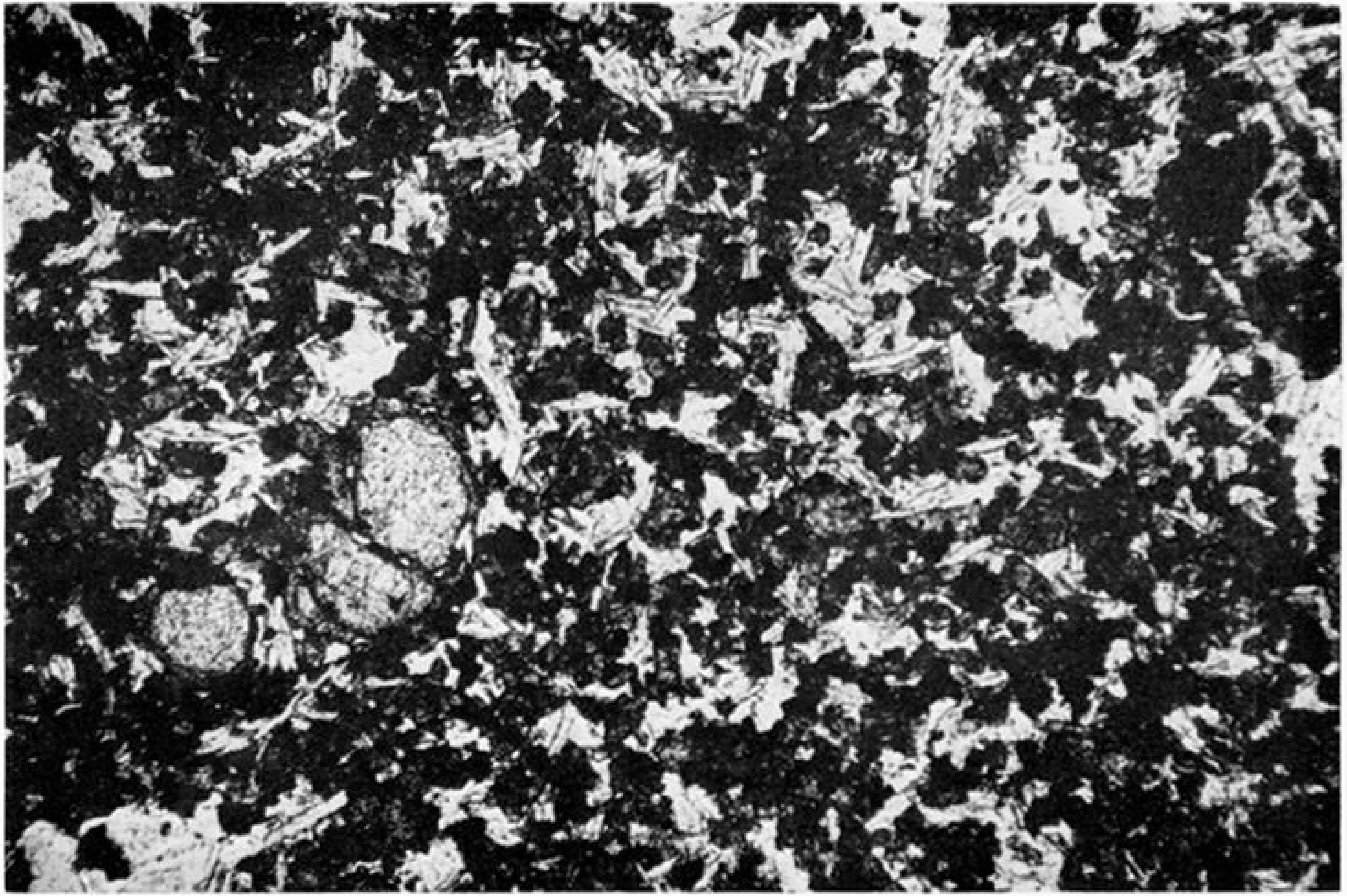


FIGURE 69. *Olivine basalt* (6). Volcanic conduit in Main Cliffs, 300 yards west of Caves Gulch. Small phenocrysts of olivine in a groundmass of plagioclase, pyroxene and iron ore. Plane polarized light. (Magn. ×34.)

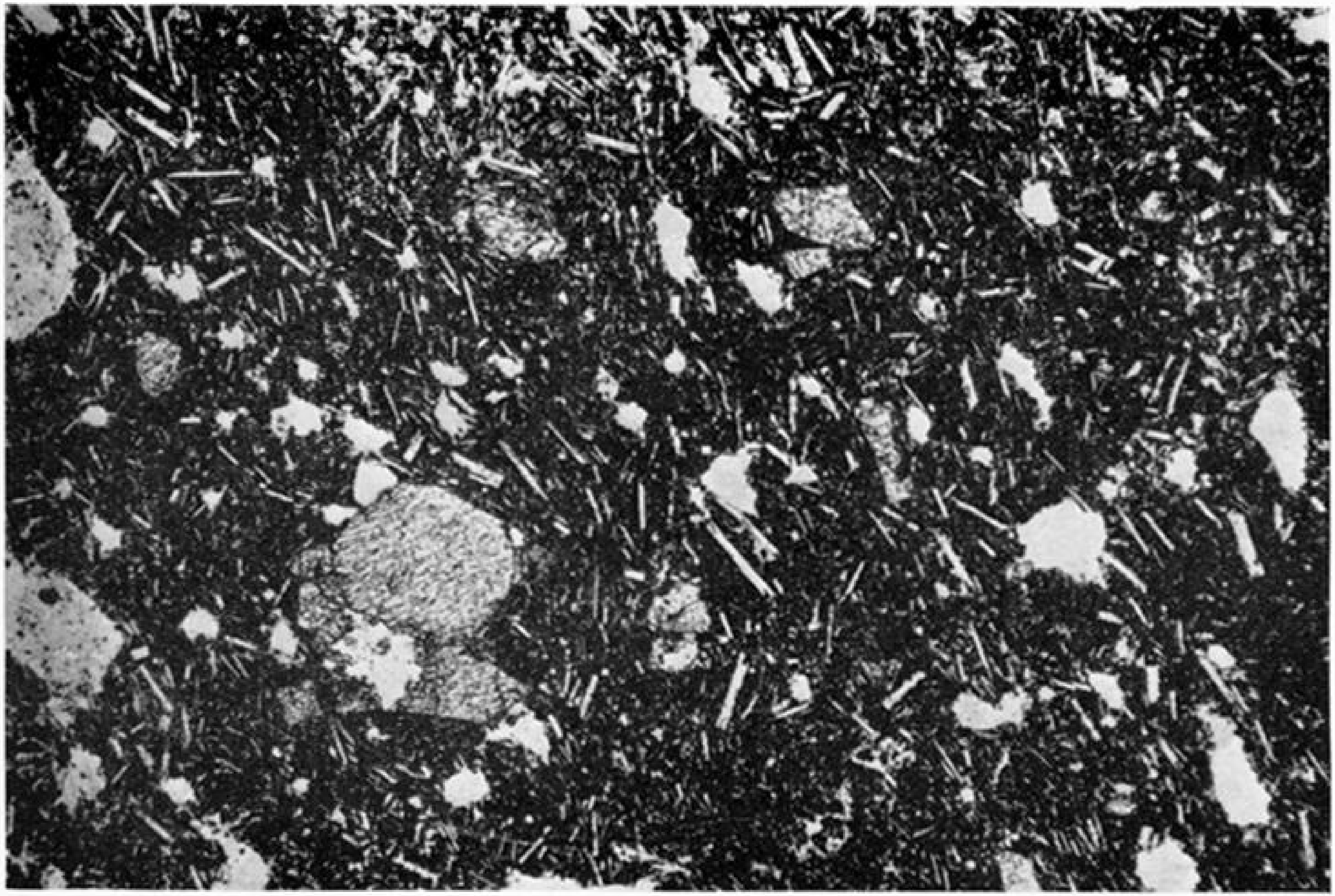


FIGURE 70. *Trachybasalt* (466). Dyke, east side of headland to the east of the waterfall, Inaccessible. Small phenocrysts of olivine in a groundmass of plagioclase, iron ore and pyroxene. Plane polarized light. (Magn. $\times 34$.)

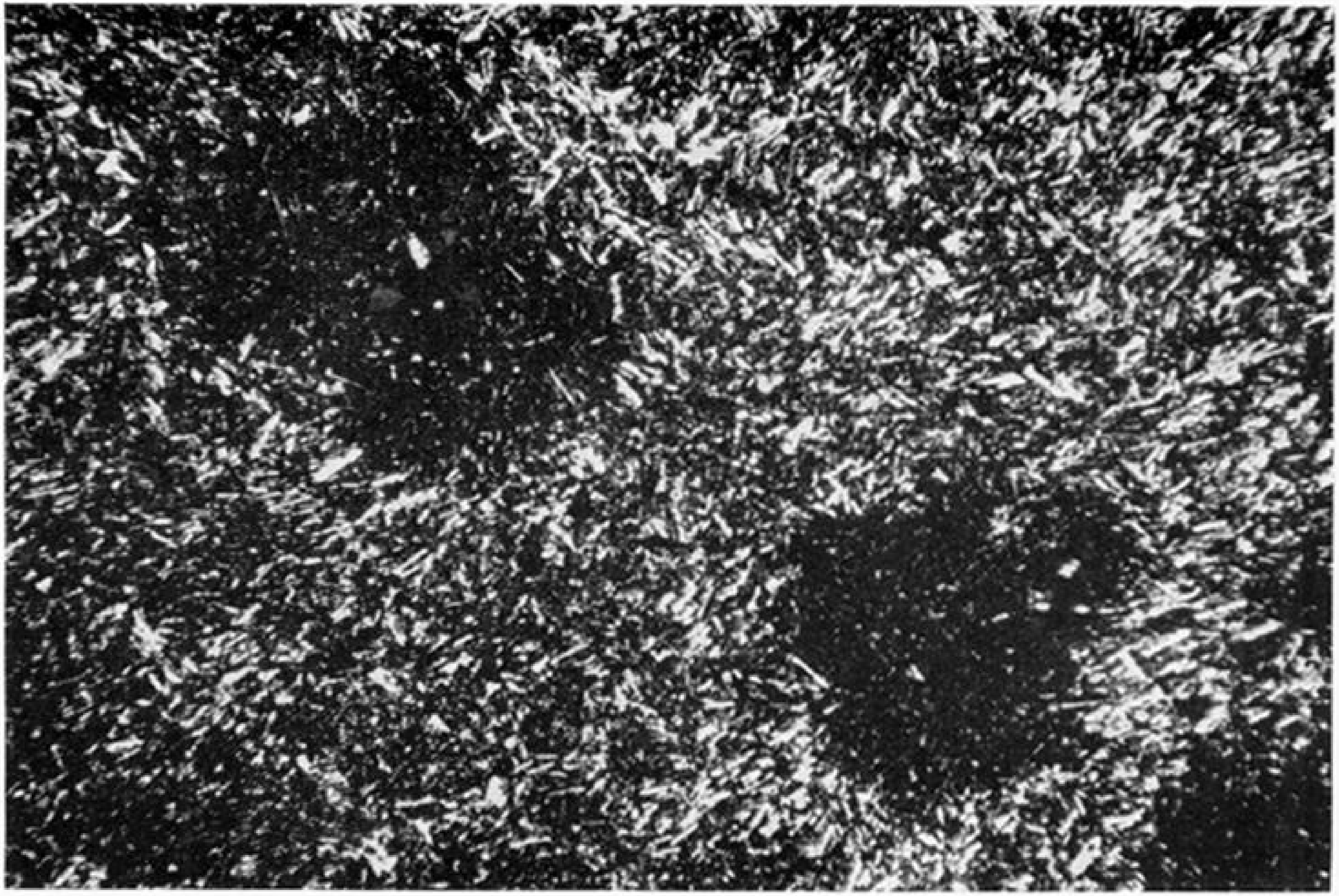


FIGURE 71. *Leucite-bearing trachybasalt* (194). Volcanic neck in Blineye parasitic centre, west end of Stony Beach. Fine grained rock consisting of crystals of plagioclase, pyroxene and iron ore. Leucite forms the mesostasis of the dark spots. Crossed polars. (Magn. ×34.)

FIGURE 72. *Leucite-bearing trachybasalt* (351). Small plug 100 yards east of summit crater lake. Leucite occurring as a cavity infilling. Crossed polars. (Magn. ×135.)

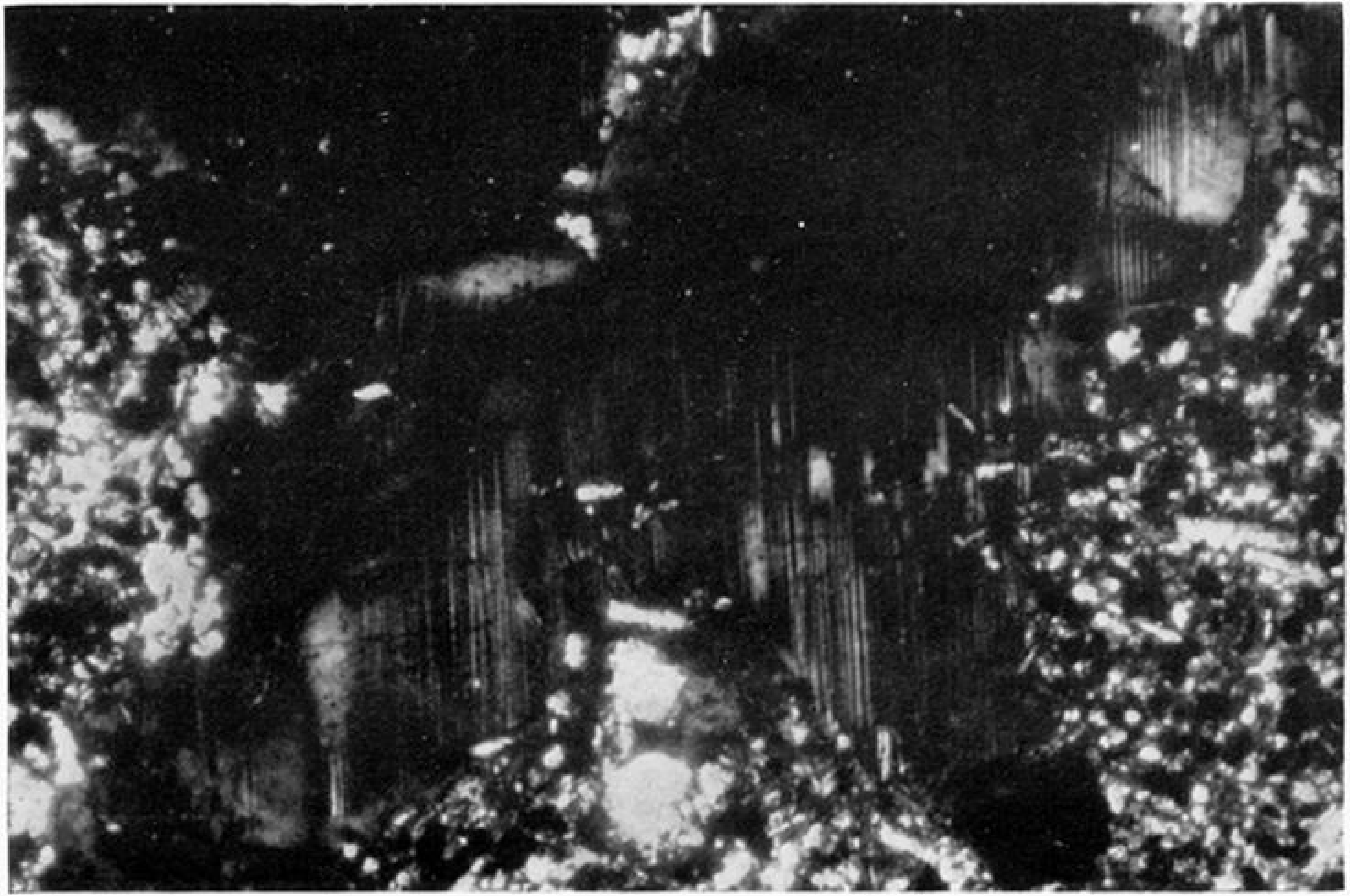


FIGURE 73. *Leucite-bearing trachybasalt* (351). Leucite occurring as the infilling of a small irregular cavity and displaying lamellar twinning. Crossed polars. (Magn. × 135.)

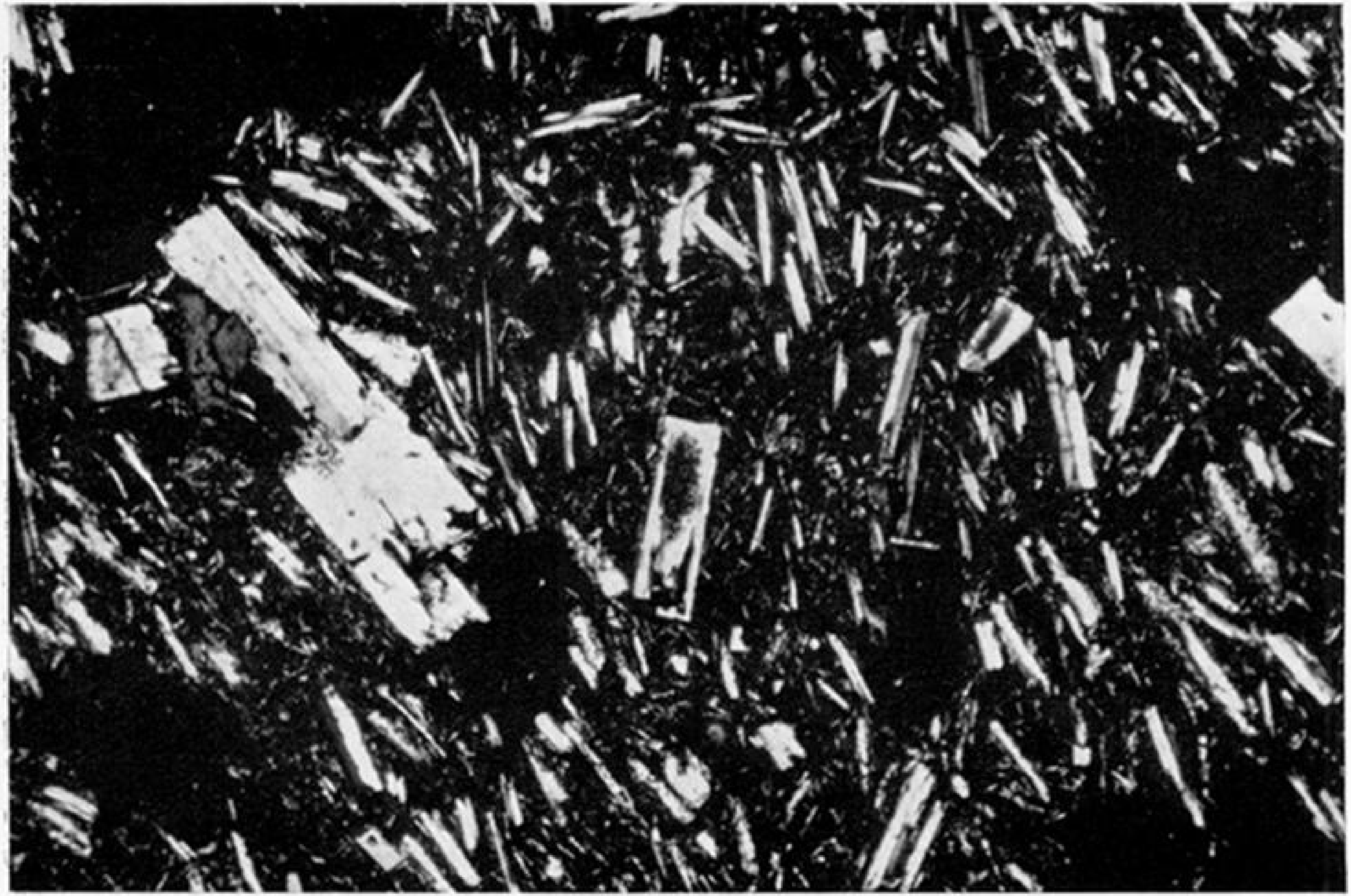


FIGURE 74. *Trachyandesite* (183). Flow from Hill-with-a-hole-in. Phenocrysts of zoned plagioclase An_{60} to An_{37} in sub-parallel orientation and microphenocrysts of pyroxene in a groundmass of plagioclase, pyroxene, alkali feldspar, ore and glass. Crossed polars. (Magn. ×34.)

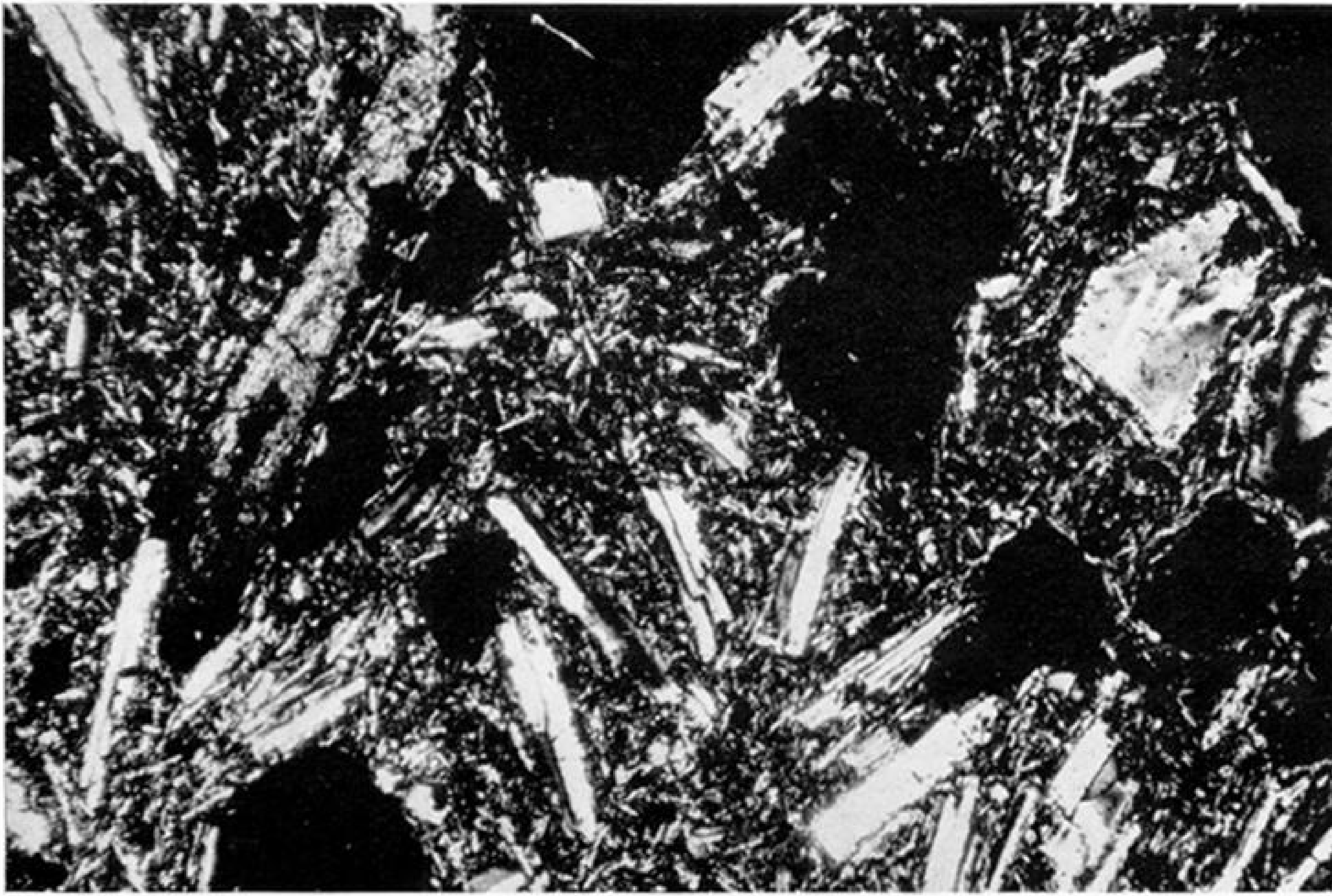


FIGURE 75. *Trachyandesite* (230). Summit of flow lobing south-east from Stony Hill. Phenocrysts of plagioclase An_{60} and basaltic hornblende in a hyalopilitic groundmass of plagioclase laths, aegirine microlites and ore in a turbid mesostasis of alkali feldspar and brown glass. Crossed polars. (Magn. $\times 34$.)

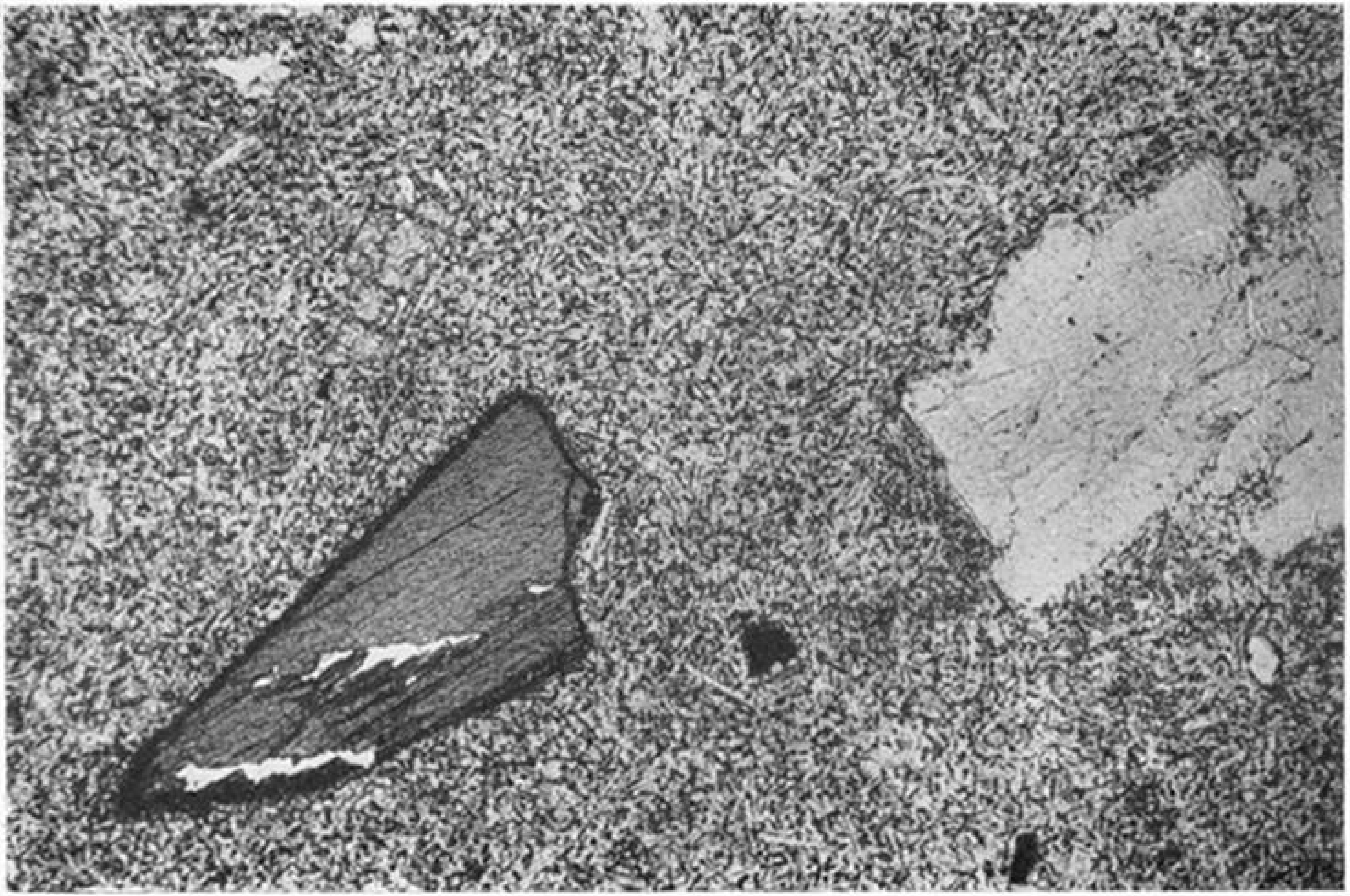


FIGURE 76. *Porphyritic trachyandesite* (572). Lava flow west side of 2nd Ridge-where-the-goat-jumped-off. Phenocrysts of partly resorbed amphibole, plagioclase An_{65} and apatite in a felted groundmass of alkali feldspar, acicular pyroxene and iron ore. Plane polarized light. (Magn. $\times$ 34.)

FIGURE 77. *Trachyandesite* (616). Central lava, 1961 Eruptive Centre. Phenocryst of amphibole in a groundmass of sub-parallel laths of zoned plagioclase An_{58} to An_{40}, pyroxene and iron ore. Crossed polars. (Magn. $\times 34$.)

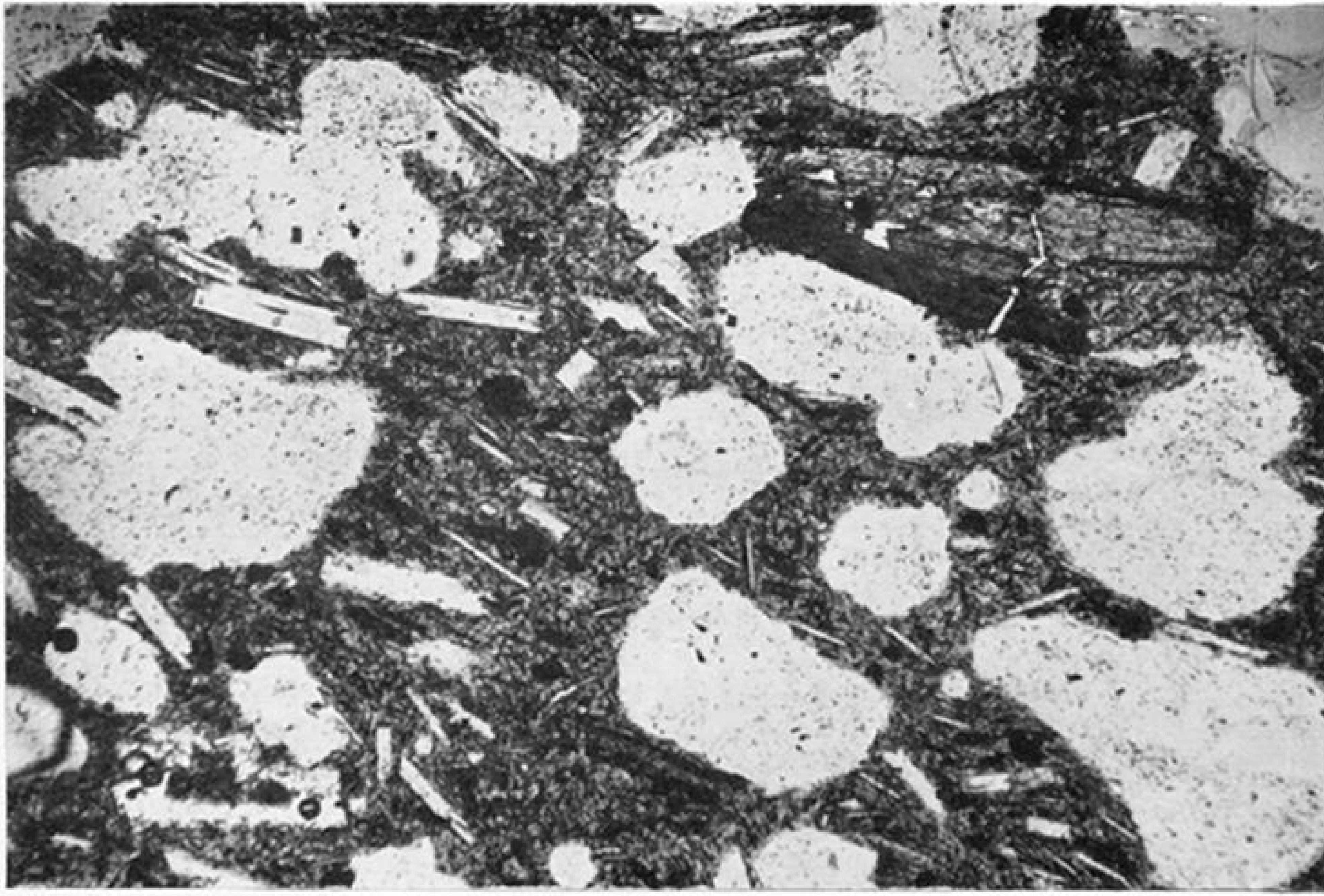


FIGURE 78. *Trachyandesite* (22). Large bomb 50 yards from west flank of 1961 Eruptive Centre. Phenocrysts of basaltic hornblende and microphenocrysts of plagioclase An_{55} in a groundmass consisting of plagioclase and pyroxene microlites and brown glass. Plane polarized light. (Magn. $\times 34$.)

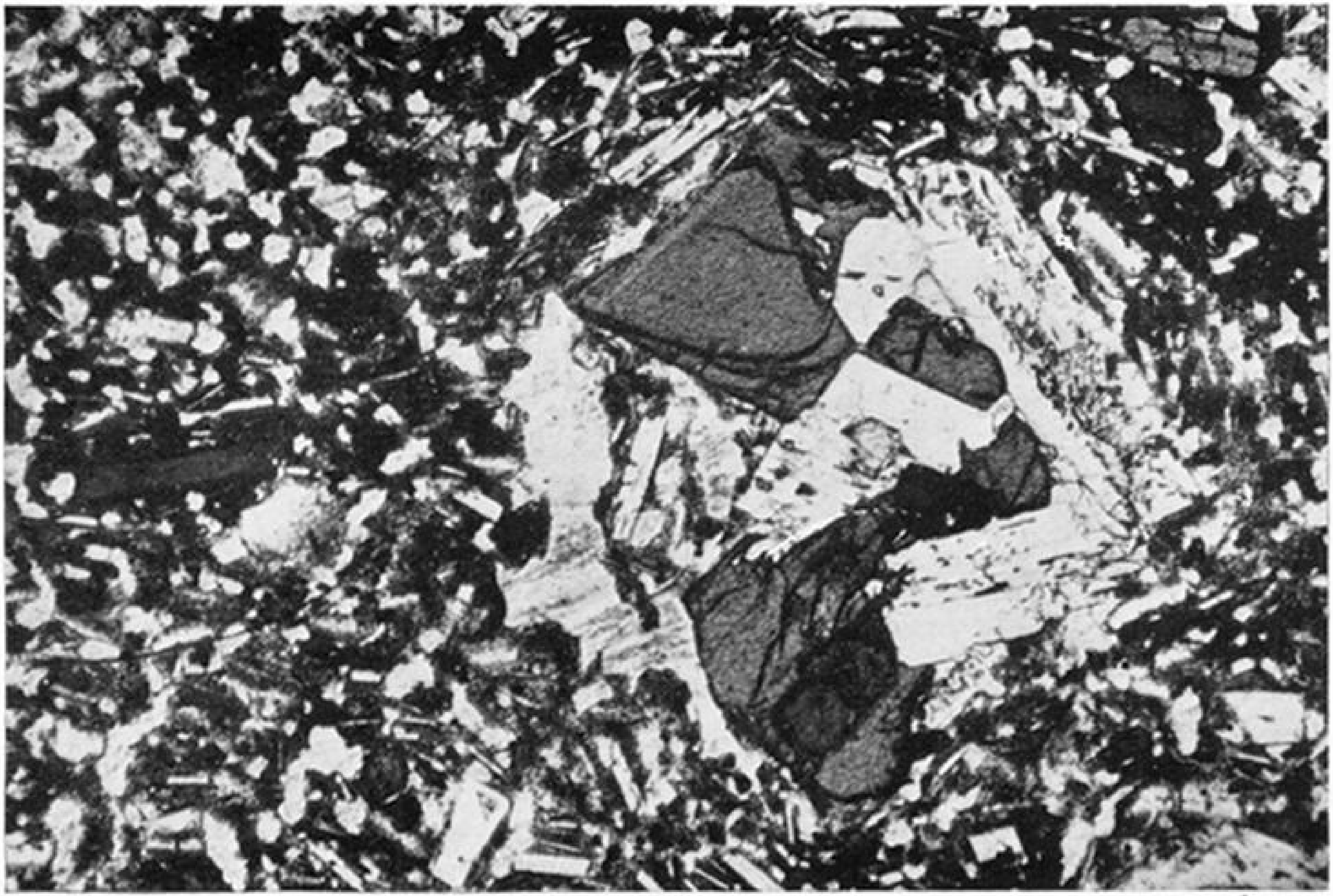


FIGURE 79. *Xenolith in trachyandesite* (518). West flank of dome, 1961 Eruptive Centre. Small xenolith consisting of pyroxene, plagioclase An_{75} and sphene in a trachyandesite consisting of finer-grained feldspar, pyroxene and iron ore. Plane polarized light. (Magn. $\times 34$.)

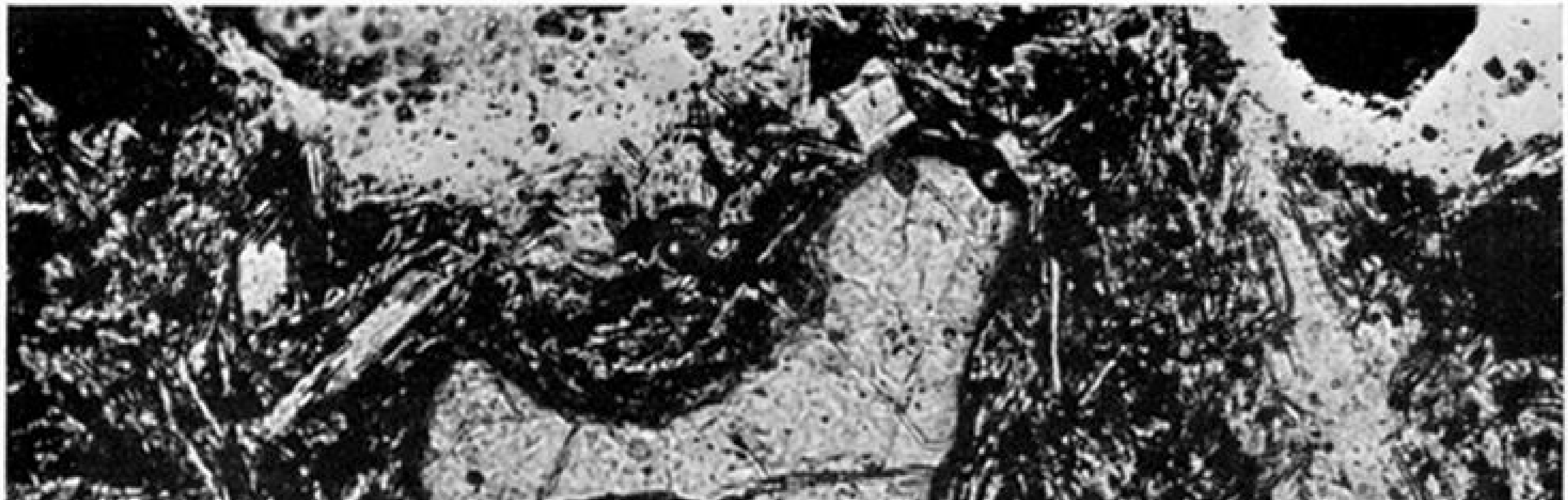


FIGURE 80. *Trachyandesite* (72). Western flow, 1961 Eruptive Centre. A crystal of haüyne, surrounded by pyroxene, feldspar and iron ore. Plane polarized light. (Magn. × 135.)

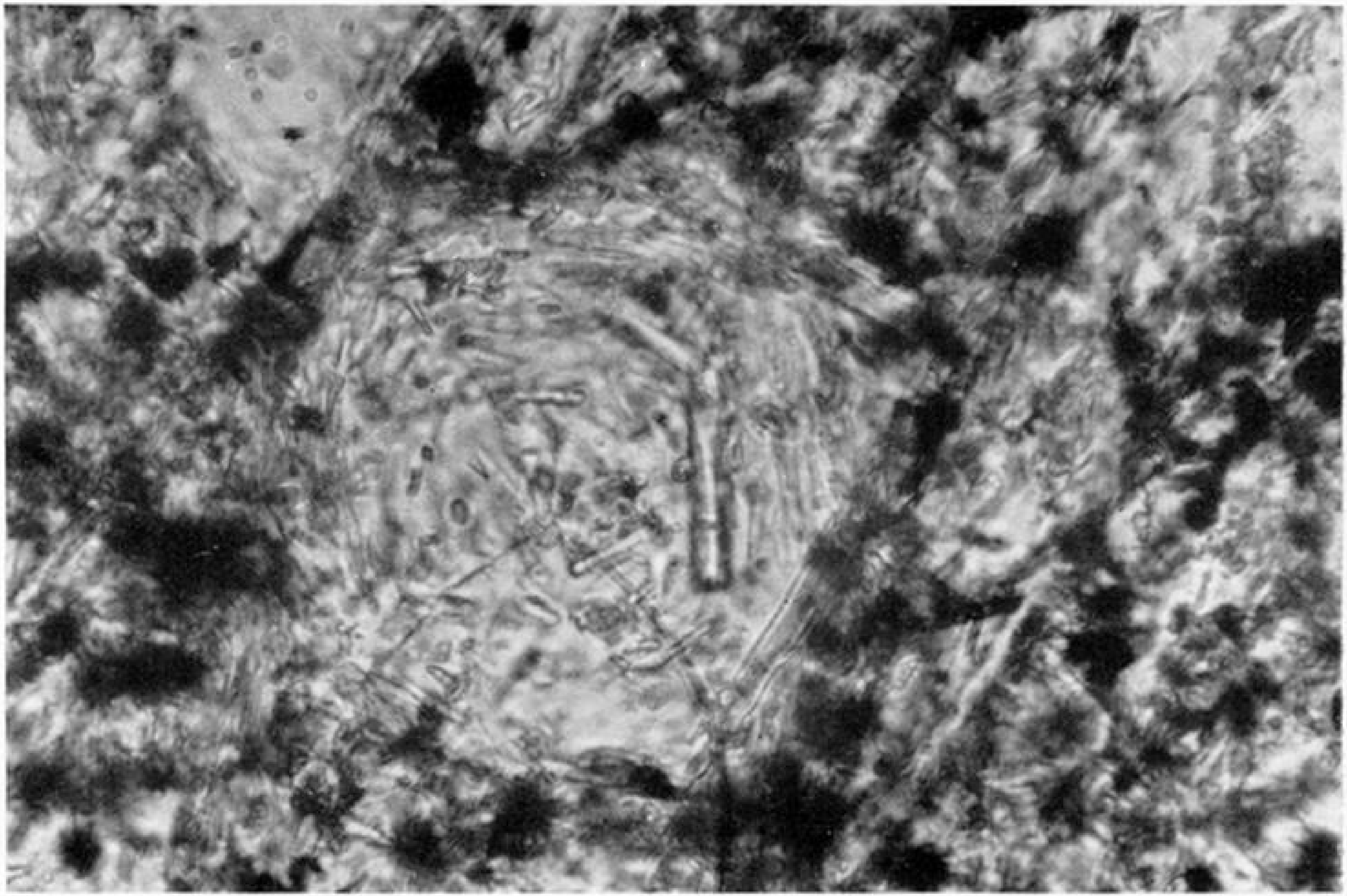


FIGURE 81. *Trachyandesite* (345). A minute rounded grain of leucite containing tangentially arranged rods of pale-green pyroxene. Plane polarized light. (Magn. ×135.)

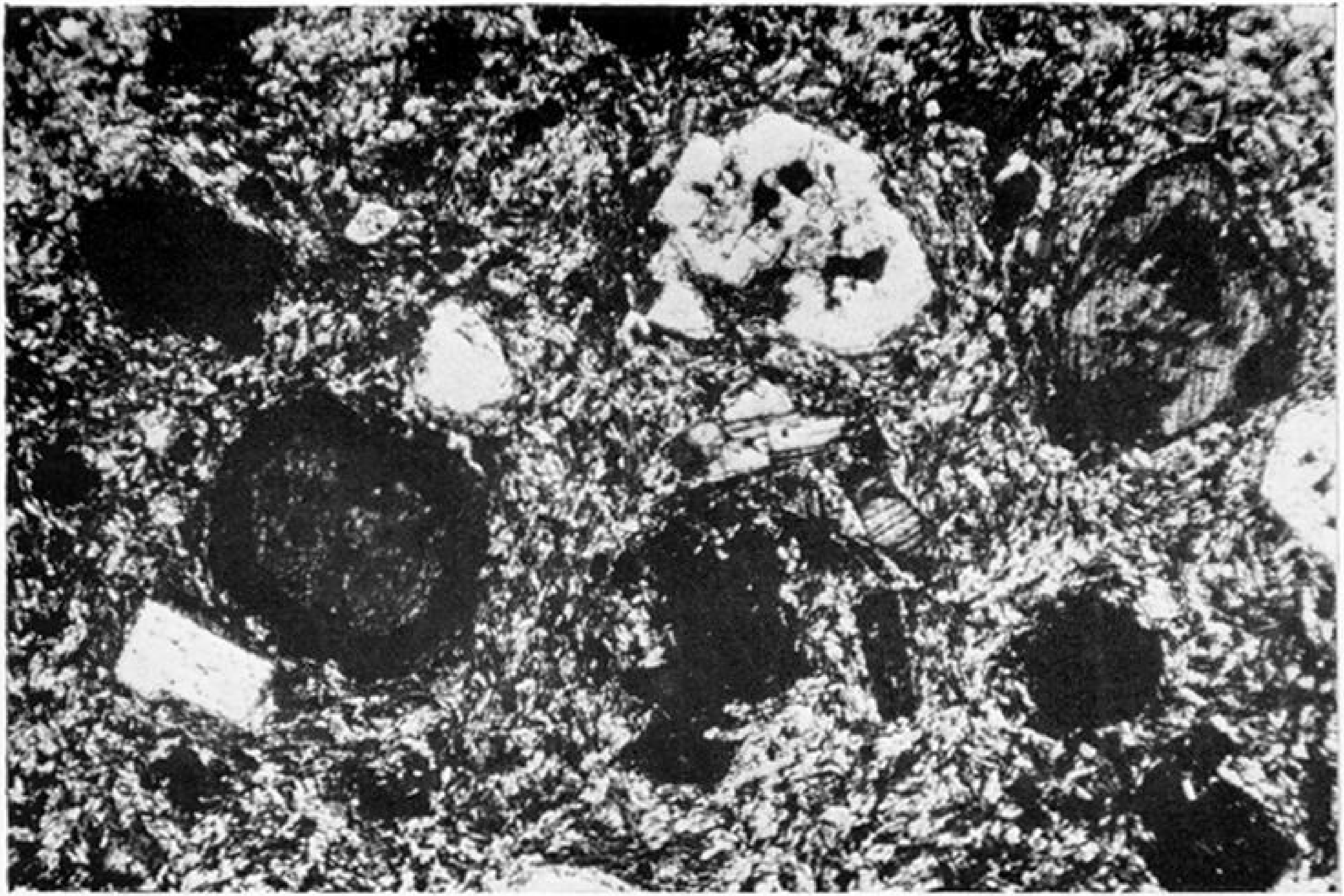


FIGURE 82. *Plagioclase trachyte* (412). 200 yards north-east of North Pond, Nightingale I. Phenocrysts of resorbed amphibole, pyroxene and plagioclase in a groundmass of alkali feldspar and aegirine-augite. Crossed polars. (Magn. ×14.)

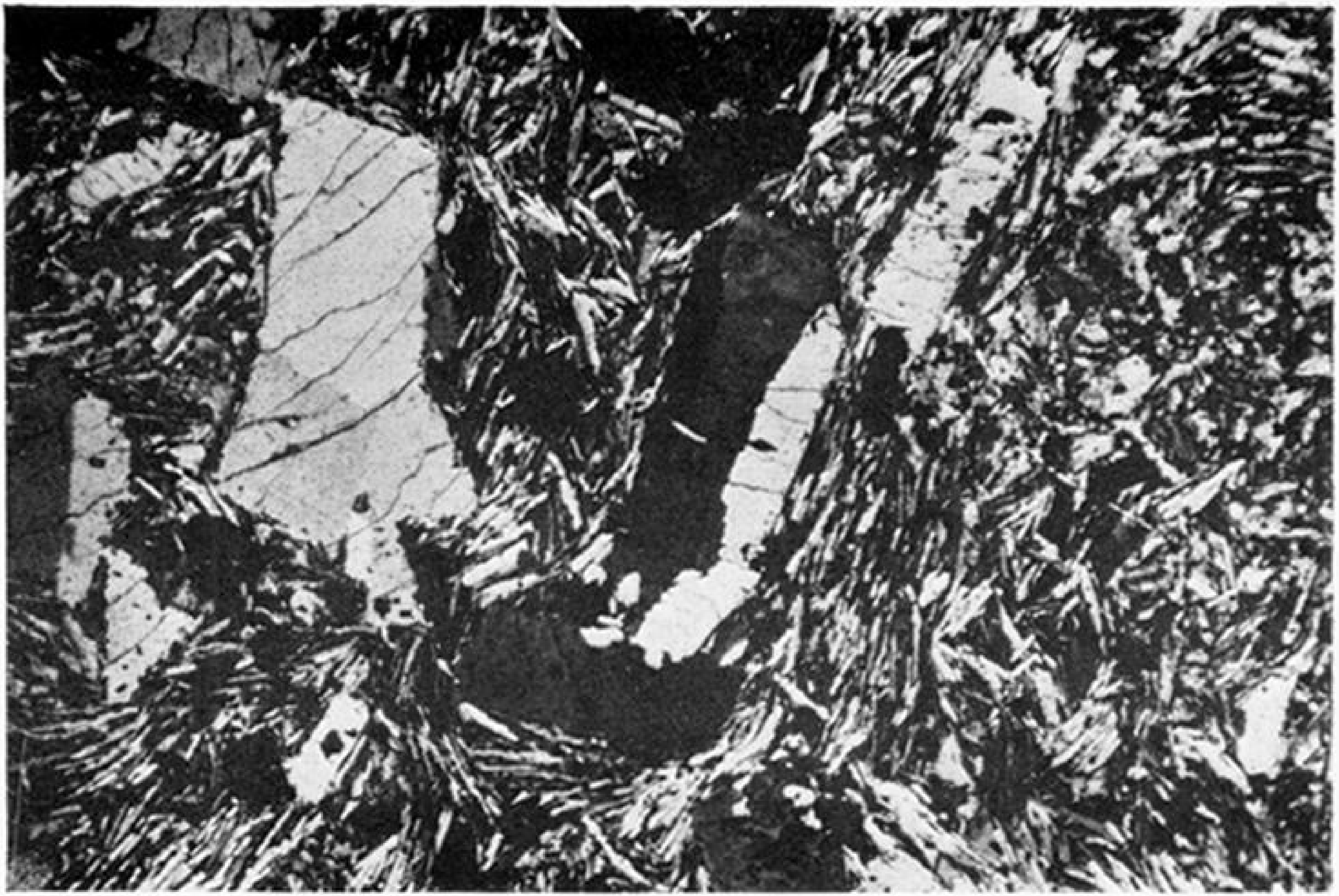


FIGURE 83. *Alkali feldspar trachyte* (439). Columnar jointed lava beneath tuff on hardie off Sea hen Rocks, Nightingale I (plate 26). Abundant phenocrysts of alkali feldspar in a groundmass of alkali feldspar, aegirine-augite and iron ore. Crossed polars. (Magn. ×14.)

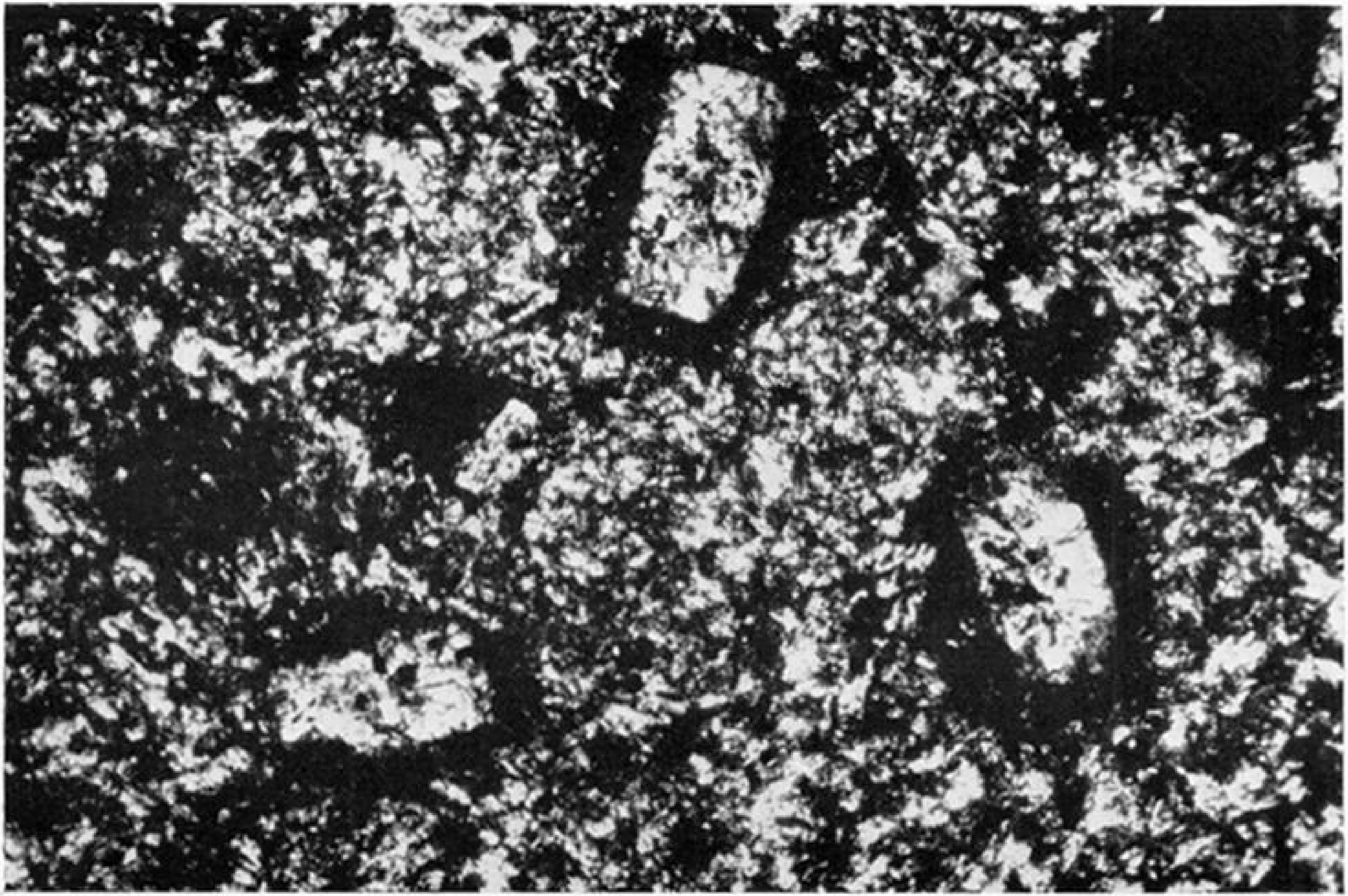


FIGURE 84. *Phonolitic alkali feldspar trachyte* (30). Stock-like mass west of Settlement Quarry. Small phenocrysts of nepheline with a dark alteration rim. The groundmass consists of alkali feldspar, aegirine-augite and iron ore. Crossed polars. (Magn. × 34.)

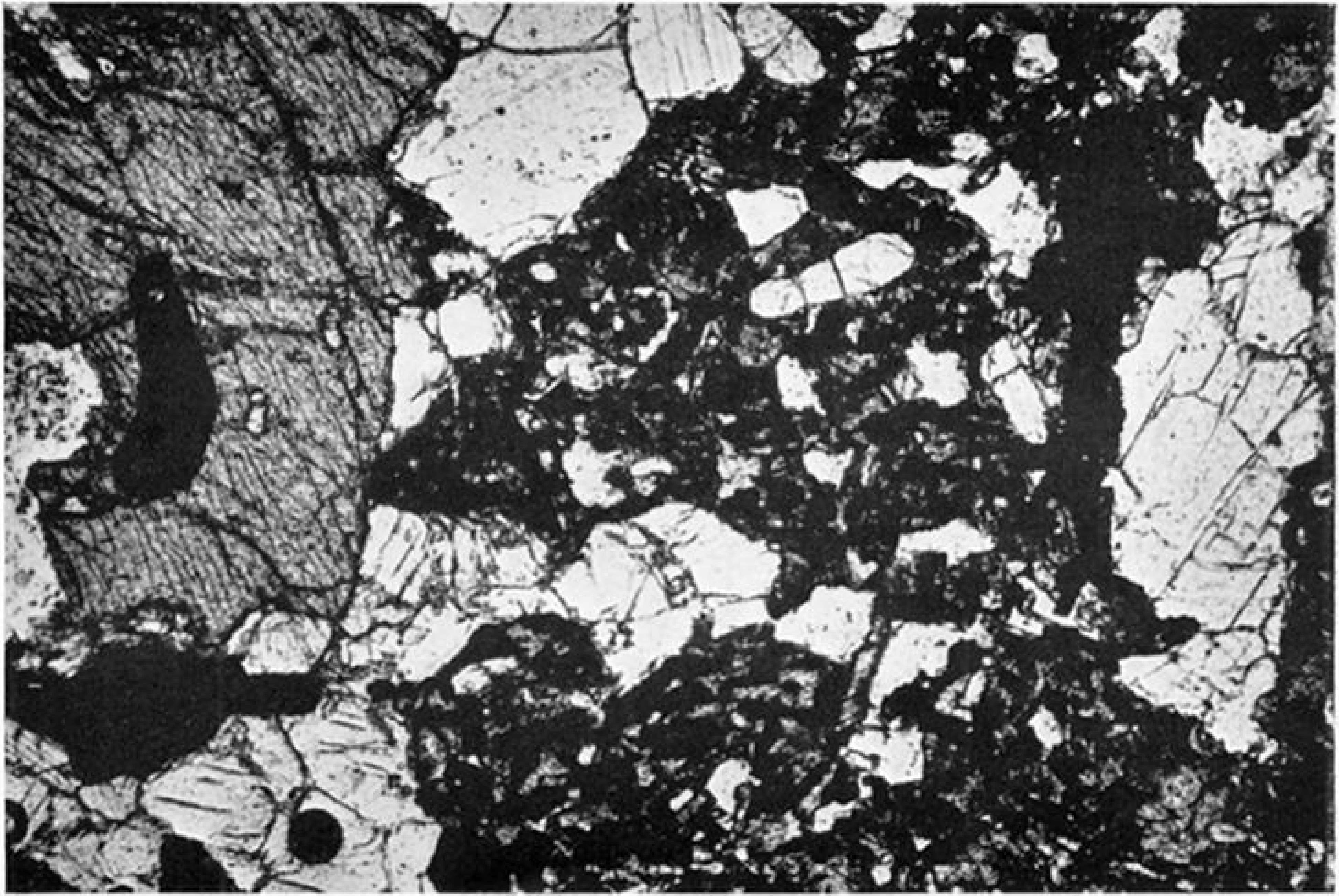


FIGURE 85. *Gabbroic xenolith* (104). In trachybasalt at east end of Sandy Point. Pyroxene, plagioclase and iron ore; the granular mass in the centre of the photograph represents completely altered amphibole. Plane polarized light. (Magn. ×34.)

FIGURE 86. *Gabbroic xenolith* (298). From Hackel Hill lava, 200 yards south of Hackel Hill. Fresh amphibole, plagioclase (labradorite-bytownite range) and clot of apatite. Plane polarized light. (Magn. ×14.)

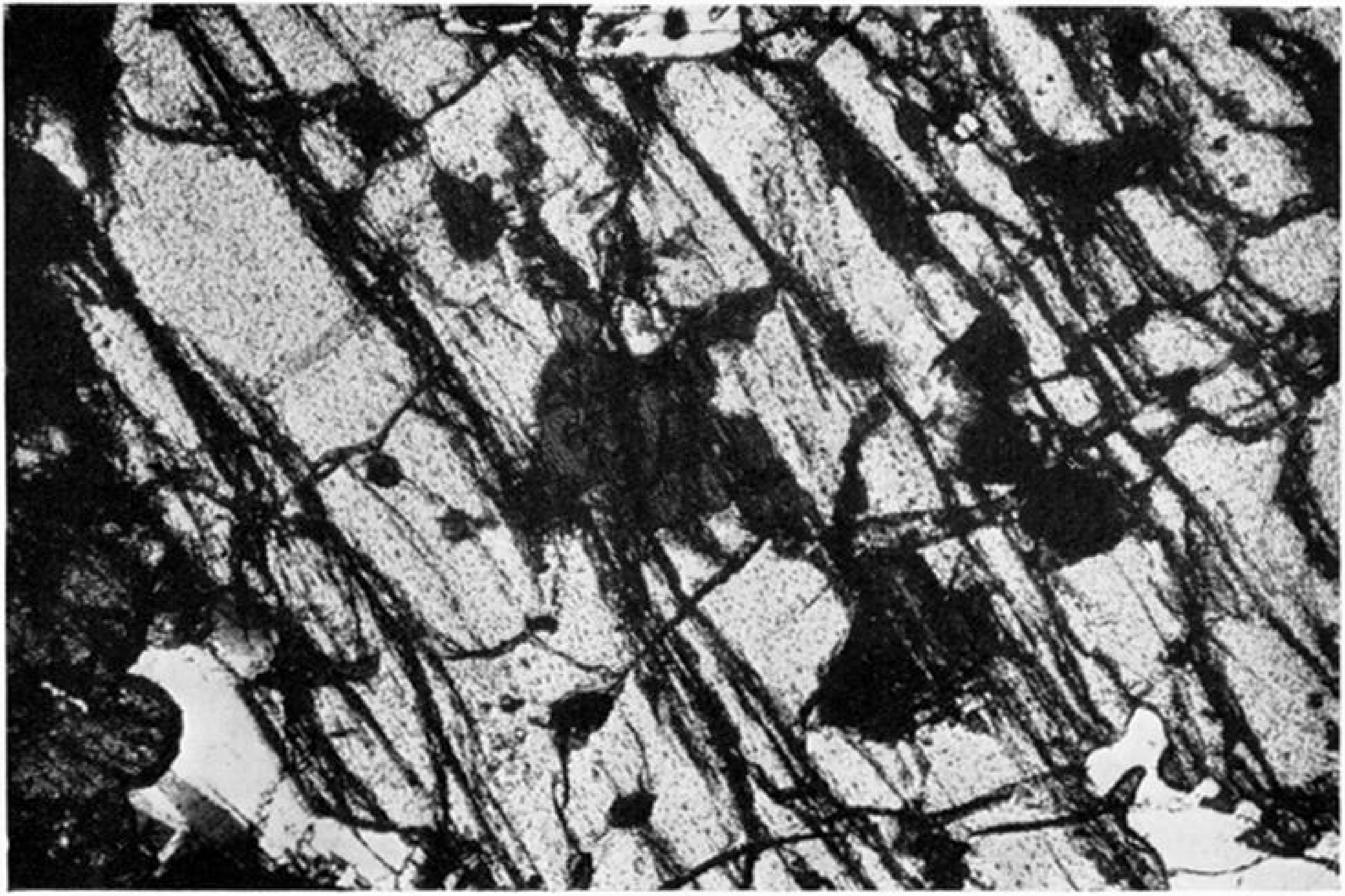


FIGURE 87. *Gabbroic xenolith* (165). From prominent red bluff 600–700 ft. O.D. between West Jews and East Jews Point. Shows clinopyroxene (light coloured) altering to basaltic hornblende (dark). Crossed polars. (Magn. $\times$ 34.)

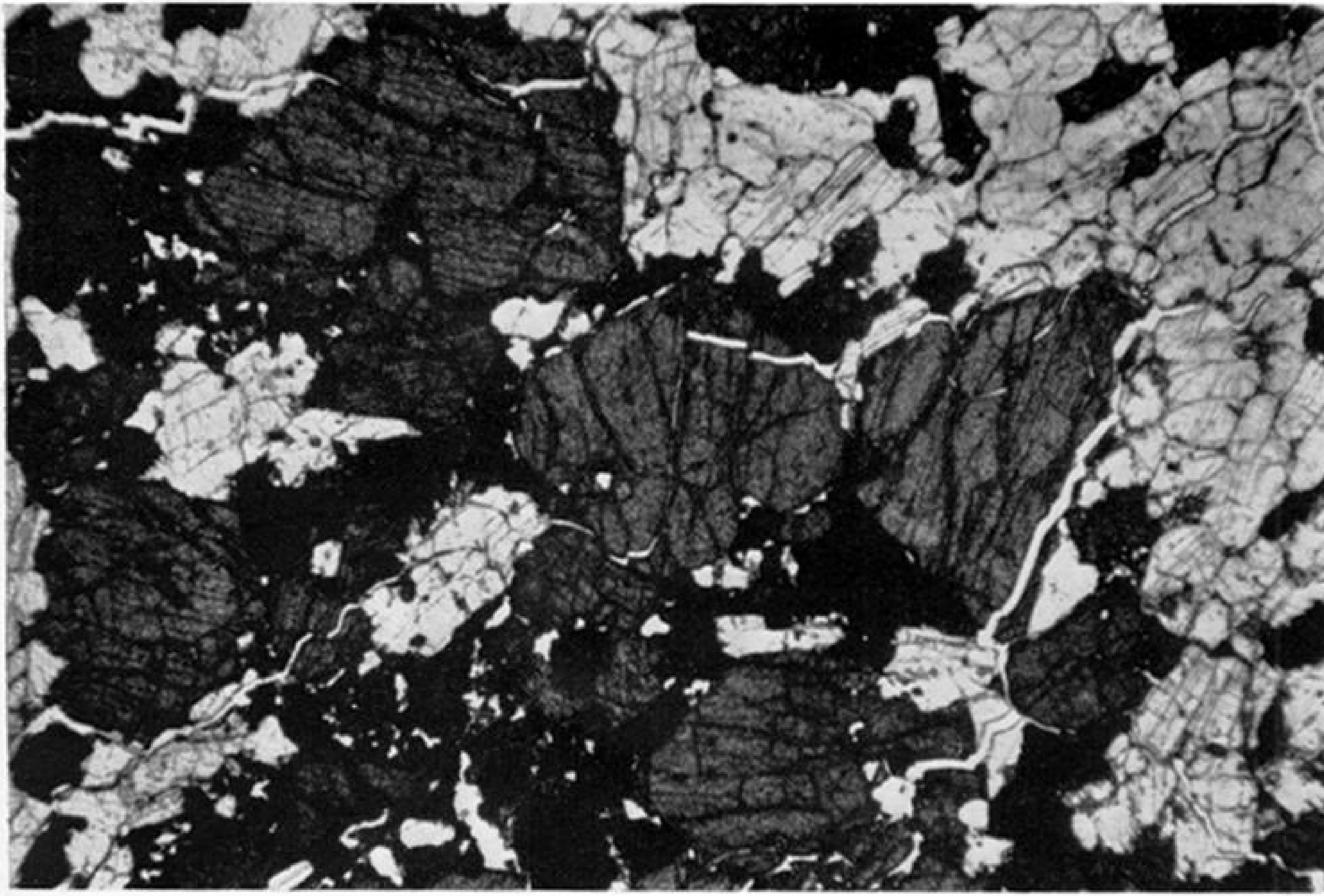


FIGURE 88. *Gabbroic xenolith* (TX5). Locality unknown: collected for R. W. Le M. by Islanders in 1956. Coarsely crystalline pyroxene, plagioclase and iron ore. Plane polarized light. (Magn. ×14.)

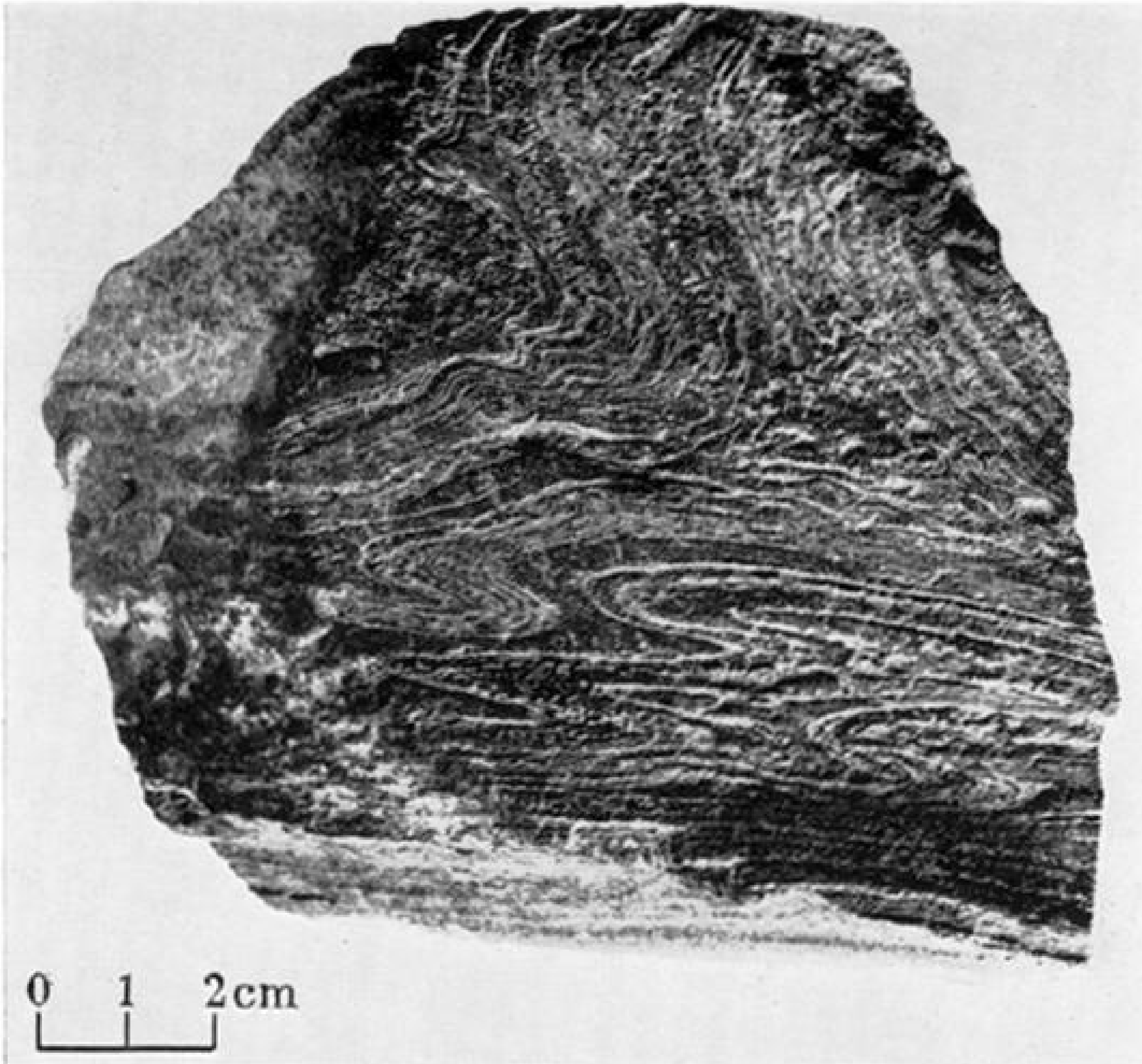


FIGURE 89. *Flow-banded trachybasalt* (117). Sandy Point, 100 yards north of east end of Sandy Point Gulch. Weathered surface: flow seems to be due largely to concentration of femic constituents, obscure when examined under microscope.

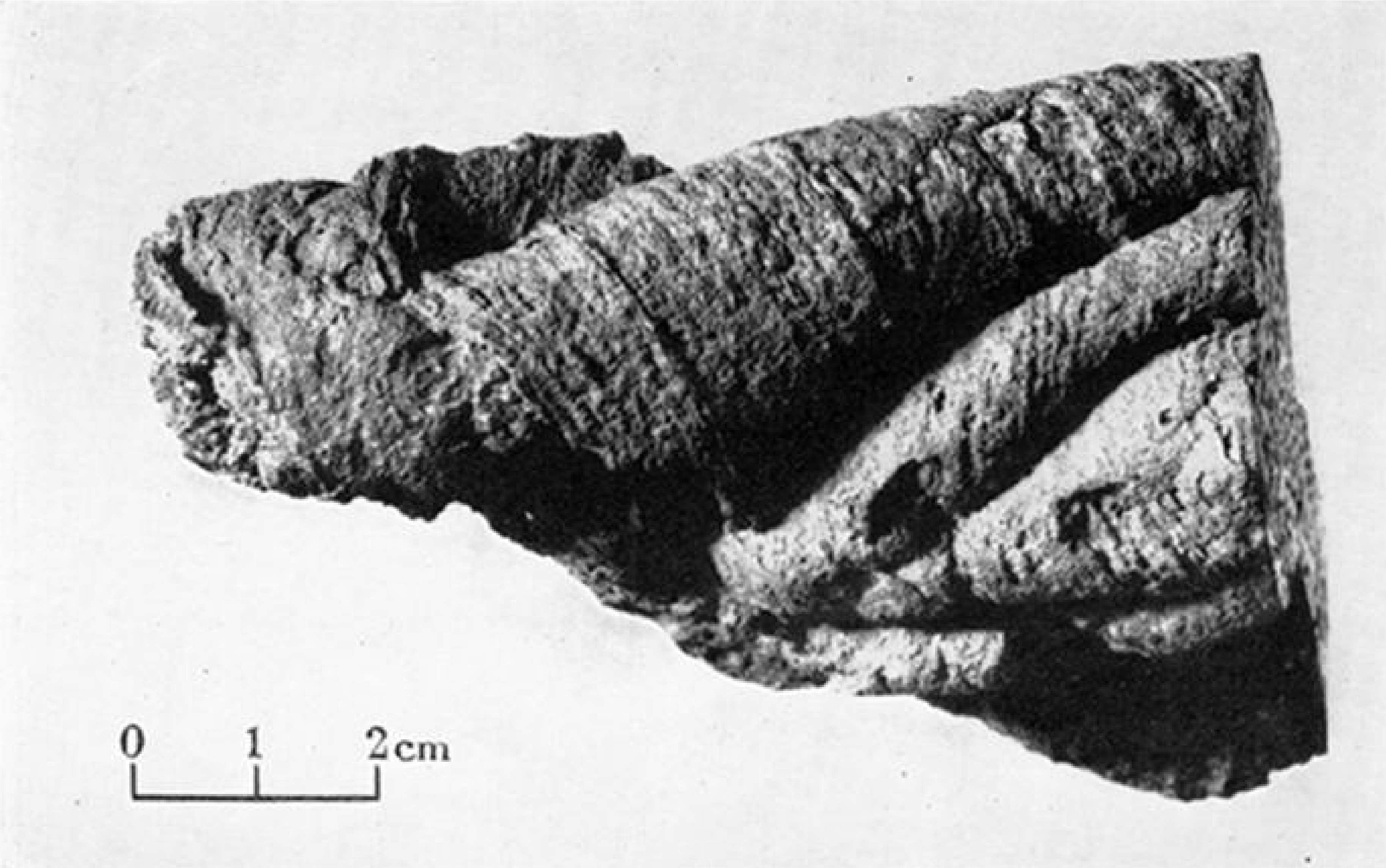


FIGURE 90. Ropy surface to thin basalt flow (F 10002, Leeds Collection). Fems Gulch 260 yards from Snell's Beach. Shows convolute form of the 'ropes' and the ribbing on the surface.

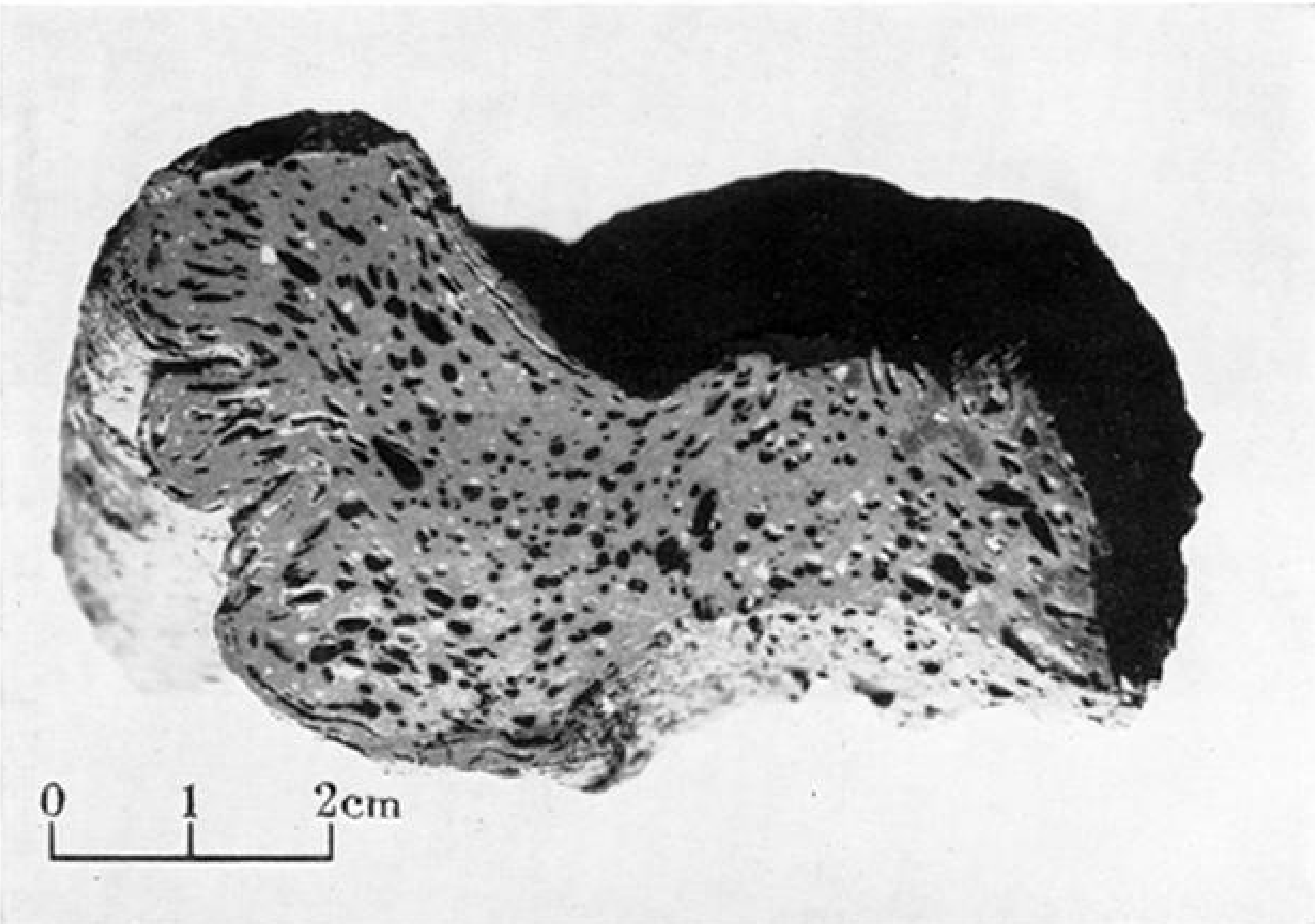
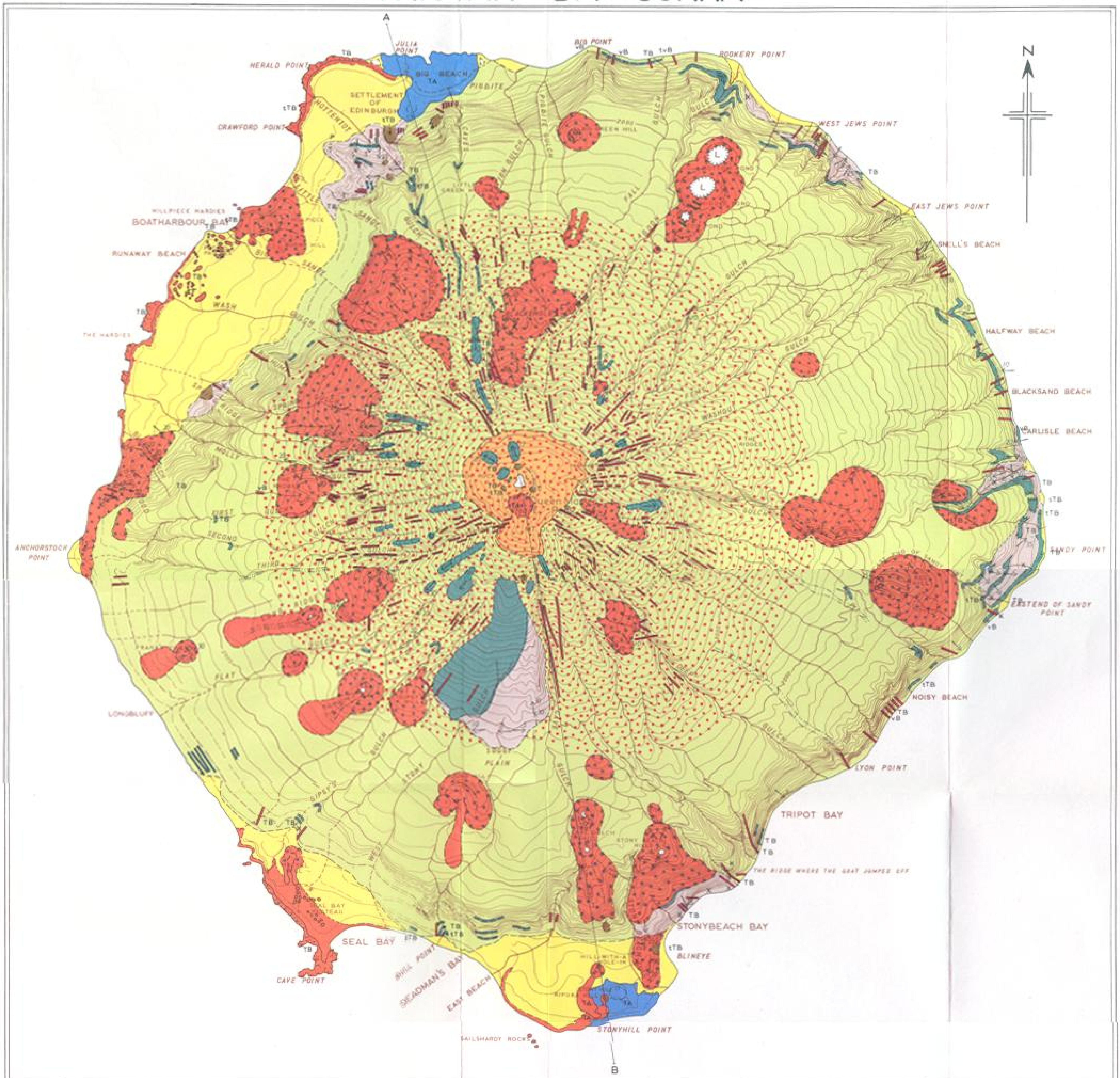


FIGURE 91. As figure 90. Cross-section through ropy lava showing the orientation of vesicles.

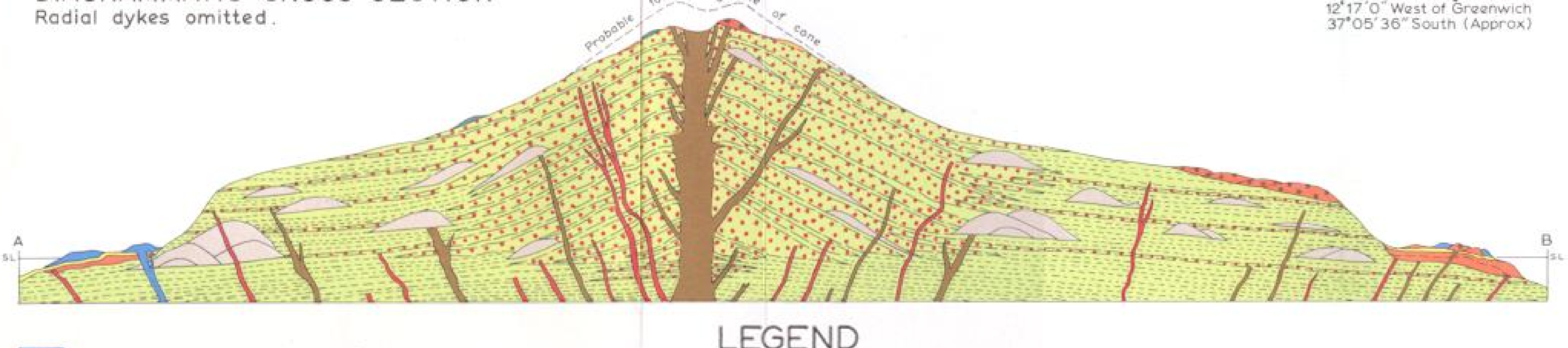
GEOLOGICAL MAP OF TRISTAN DA CUNHA



DIAGRAMMATIC CROSS SECTION

Radial dykes omitted.

Queen Mary's Peak
12°17'0" West of Greenwich
37°05'36" South (Approx)



LEGEND

- Recent trachyandesite eruptions. {Stony Hill / Settlement (1961)}
- Alluvium. Mainly outwash deposits.
- Surface cinder cones.
- Lavas from surface cinder cones.
- Peak cinder cone.
- Main volcanic sequence:- Predominantly pyroclastic. / Predominantly lava.
- Pyroclastic centres within main sequence.
- Prominent lava flows.
- Intrusive masses.
- Dykes, near vertical unless indicated otherwise.

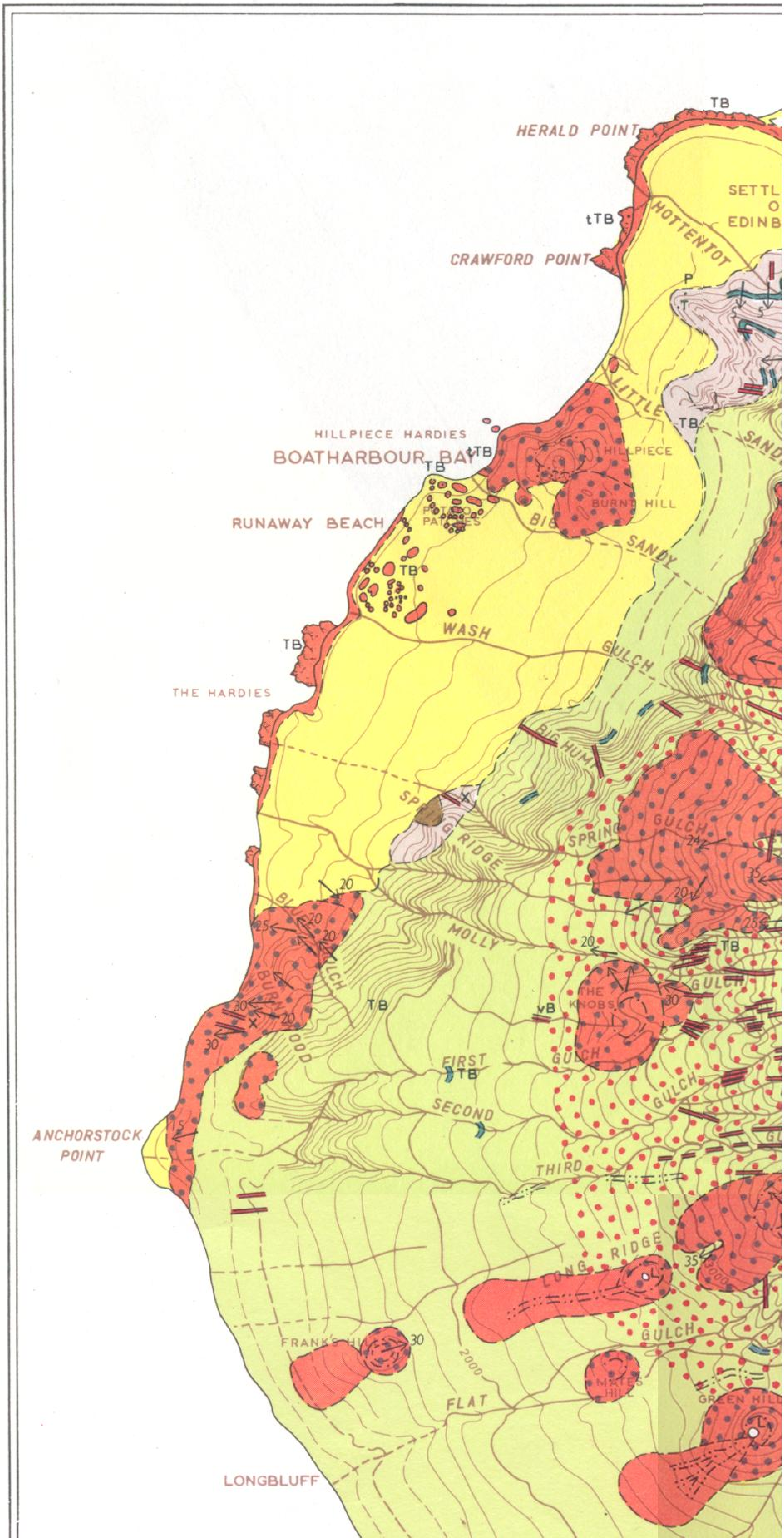
- Dip, mainly depositional, on lavas and pyroclastic deposits.
- Margin of crater.
- Margin of volcanic vent.
- Crater lake.
- Geological boundary.
- Inferred geological boundary.
- Indefinite geological boundary.
- Lava channels

HORIZONTAL AND VERTICAL SCALE

1 0 1 2

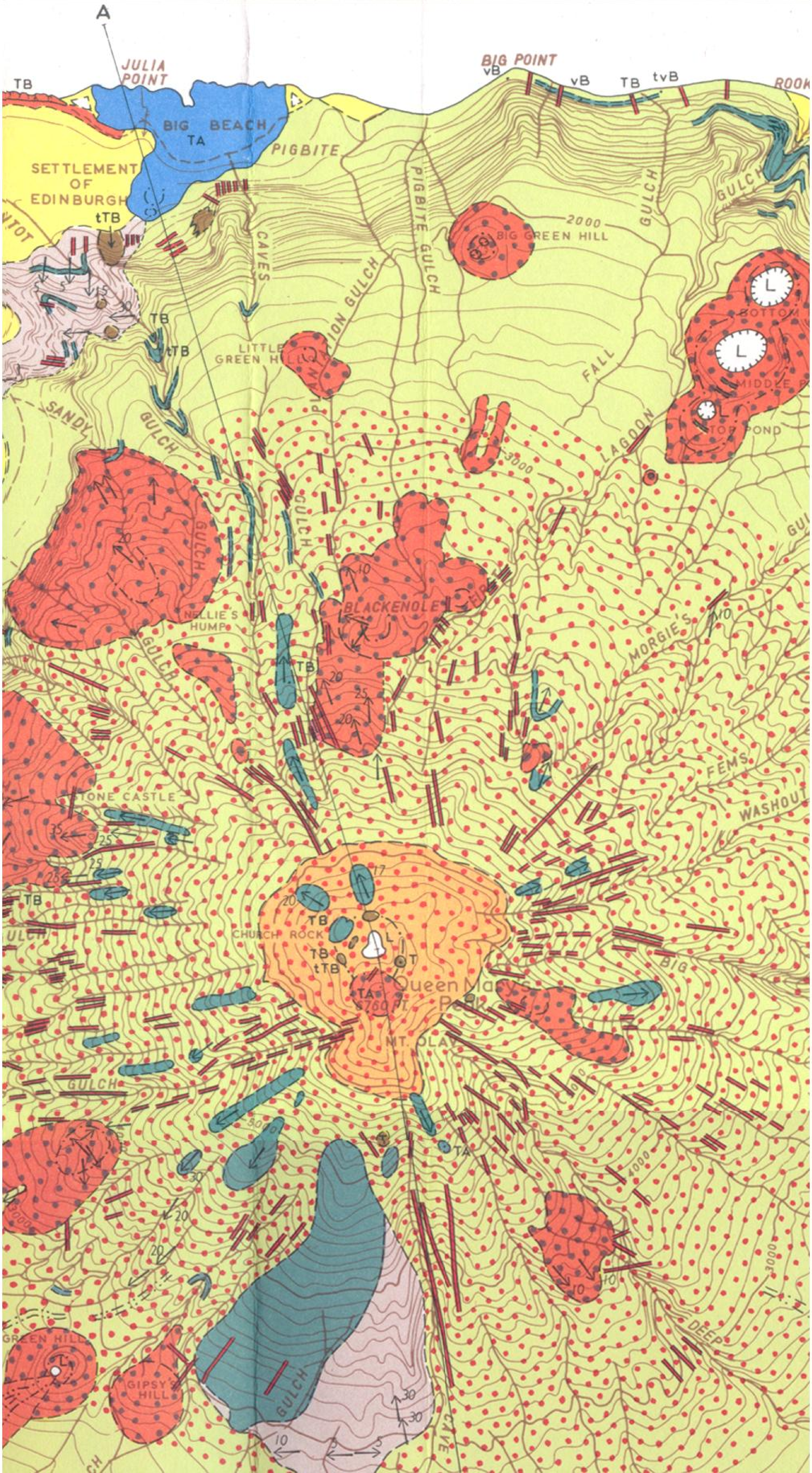
MILES

Basalt	B
Olivine Basalt	vB
Leucitic Olivine Basalt	lvB
Trachybasalt	TB
Leucitic Trachybasalt	tTB
Ankaramite	K
Leucitic Ankaramite	lK
Trachyandesite	TA
Trachyte	T
Phonolite	P
Plutonic Xenoliths	X


HERALD POINT
TB
tTB
HOTTENTOT
CRAWFORD POINT
LITTLE
HILLPIECE HARDIES
BOATHARBOUR BAY
HILLPIECE
BURNT HILL
RUNAWAY BEACH
SANDY
WASH
GULCH
THE HARDIES
BIG HUMP
SPRING
GULCH
RIDGE
MOLLY
BURNWOOD
GULCH
THE KNOBS
vB
FIRST
SECOND
THIRD
GULCH
ANCHORSTOCK POINT
LONG RIDGE
FRANK'S HILL
2000
MATES HILL
FLAT
GREEN HILL
LONGBLUFF

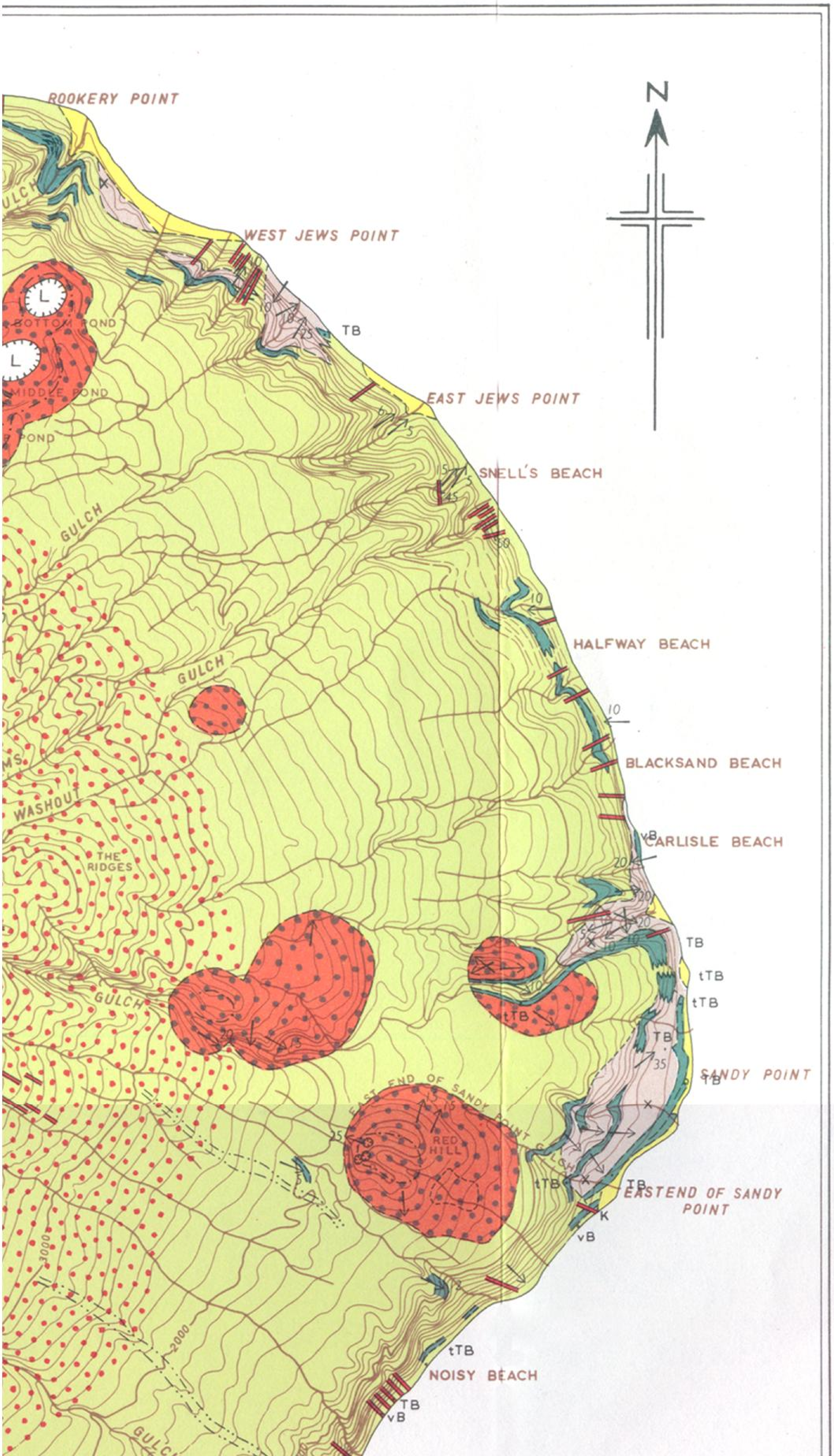
GEOLOGICAL MAP OF

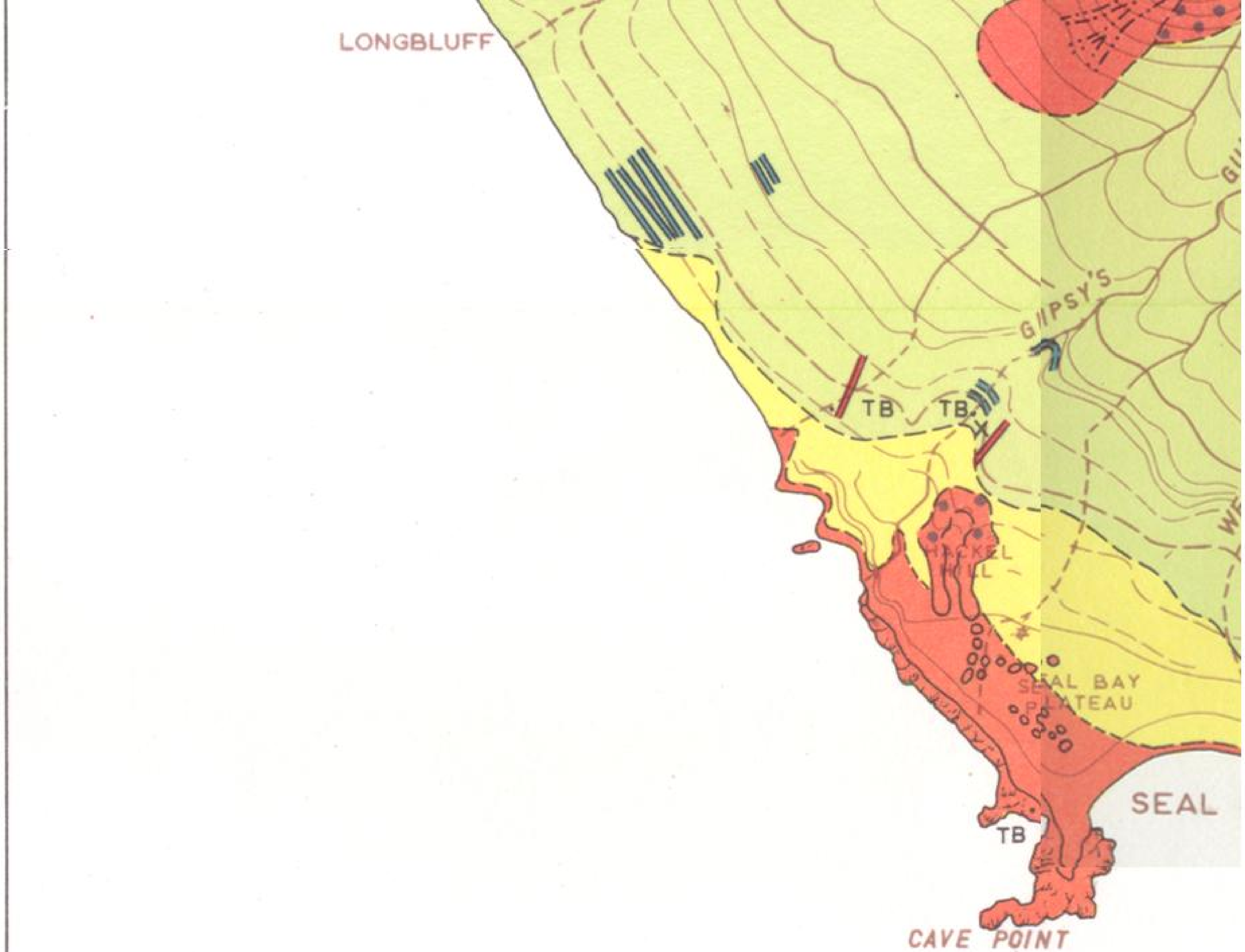
TRISTAN DA CUNHA



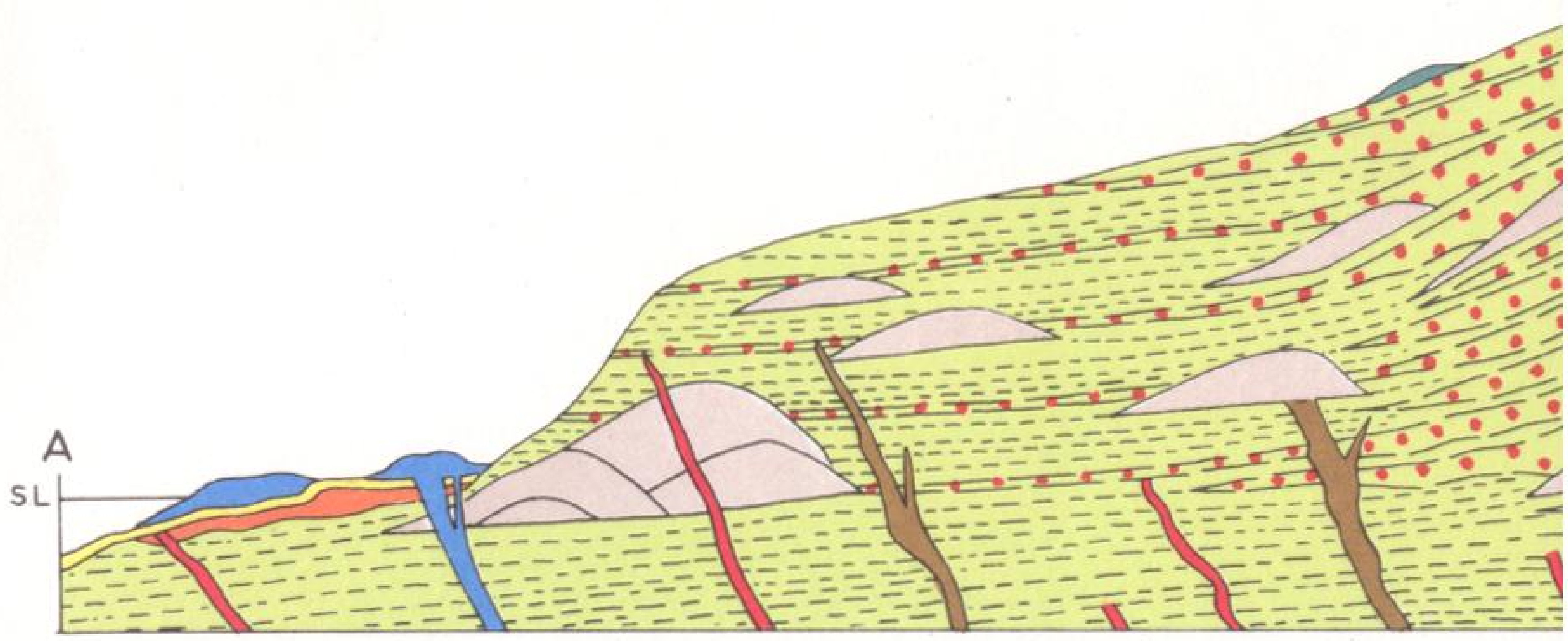
HA

Phil. Trans. A





DIAGRAMMATIC CROSS SECTION
Radial dykes omitted.



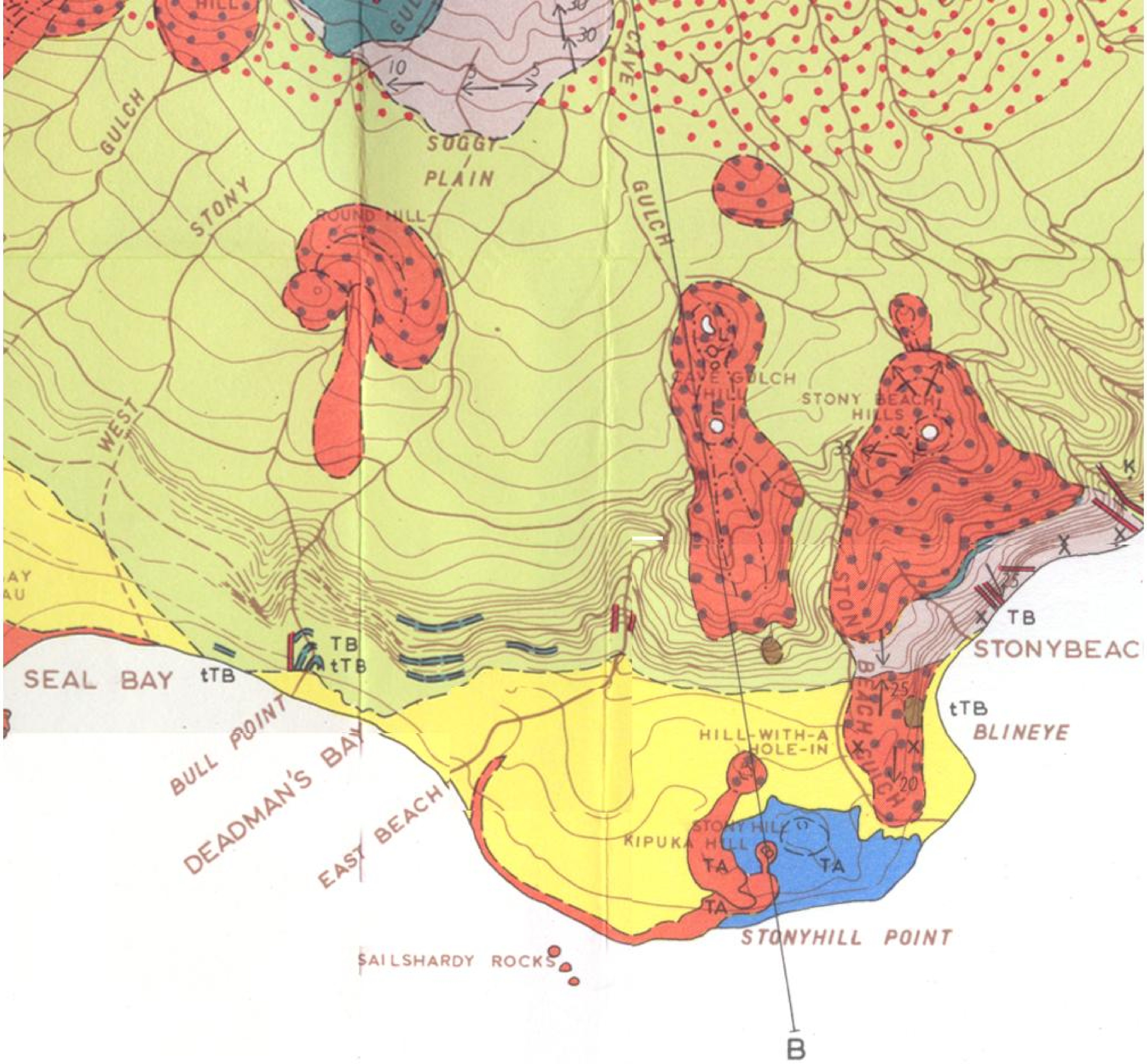
Recent trachyandesite eruptions. {*Stony Hill* / *Settlement (1961)*}

Alluvium. Mainly outwash deposits.

Surface cinder cones.

Lavas from surface cinder cones.

Peak cinder cone.



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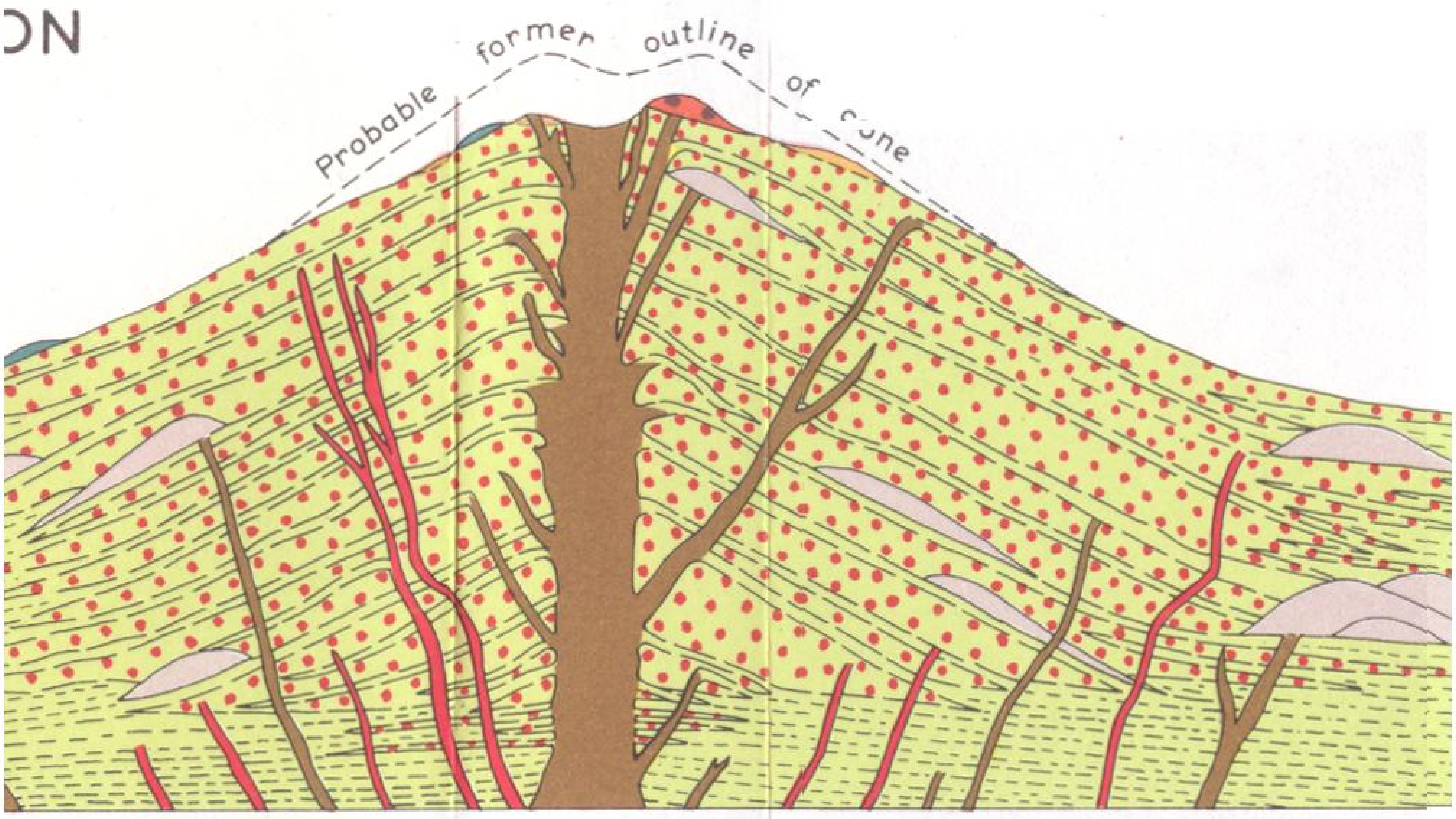


LEGEND

1961)

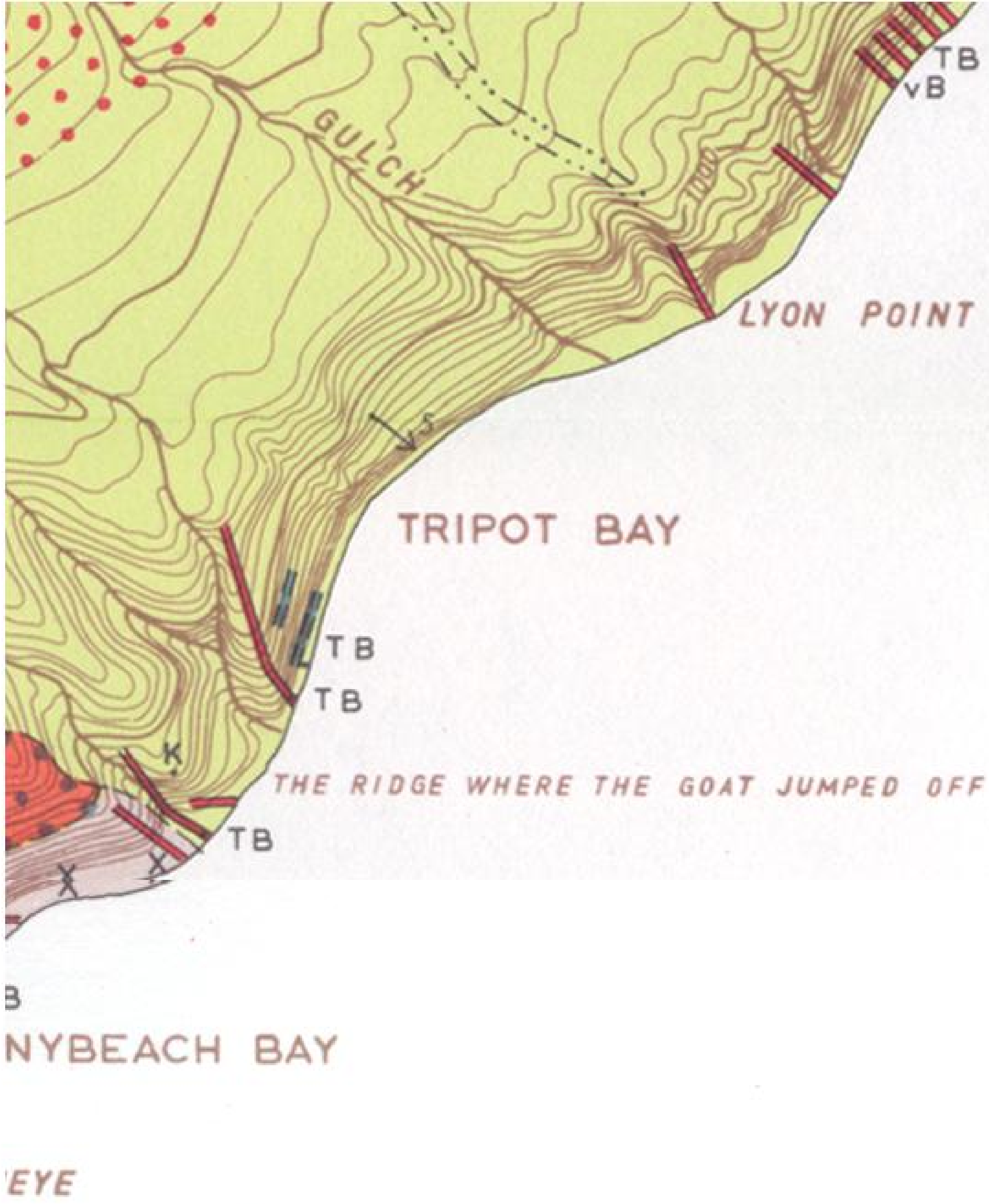
Dip, mainly depositional, on lavas and pyroc

Margin of crater.

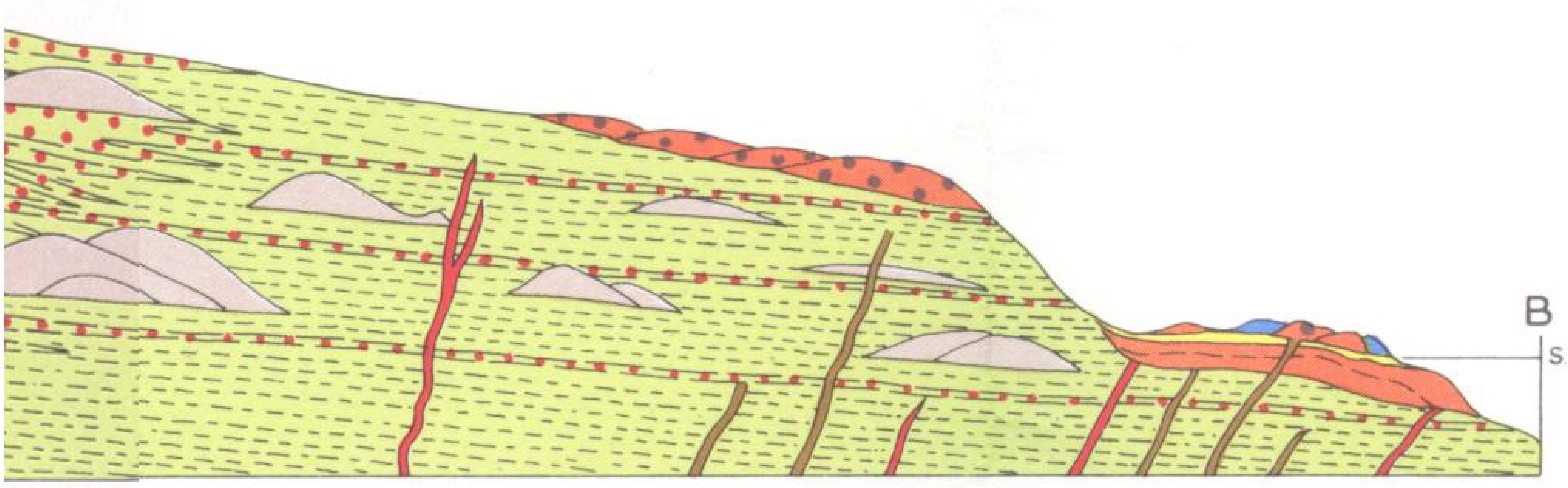
Margin of volcanic vent.

Crater lake.

Geological boundary.



Queen Mary's Peak
12°17′0″ West of Greenwich
37°05′36″ South (Approx)



' pyroclastic deposits.

Basalt _ B

Olivine Basalt _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ vB

Leucitic Olivine Basalt _ _ _ _ _ _ _ _ _ tvB

Trachybasalt _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ TB

Leucitic Trachybasalt _ _ _ _ _ _ _ _ _ _ tTB

Ankaramite _ K

Peak cinder cone.

Main volcanic sequence:- Predominantly pyroclastic.
Predominantly lava.

Pyroclastic centres within main sequence.

Prominent lava flows.

Intrusive masses.

Dykes, near vertical unless indicated otherwise.

Crater lake.

Geological boundary.

ıstic.

Inferred geological boundary.

Indefinite geological boundary.

Lava channels

HORIZONTAL AND VERTICAL SCALE

1 0 1

MILES

Leucitic Trachybasalt .... tTB

Ankaramite .... K

Leucitic Ankaramite .... tK

Trachyandesite .... TA

Trachyte .... T

Phonolite .... P

Plutonic Xenoliths X

ALE

2