BRITISH ANTARCTIC SURVEY

SCIENTIFIC REPORTS

No. 91

THE SOUTH SANDWICH ISLANDS:
I. GENERAL DESCRIPTION

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CAMBRIDGE: PUBLISHED BY THE BRITISH ANTARCTIC SURVEY: 1979
NATURAL ENVIRONMENT RESEARCH COUNCIL

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ABSTRACT

THE South Sandwich Islands are a volcanic arc of 11 islands between lat. 56°18′ and 59°28′S. and long. 26°14′ and 28°11′W. They were surveyed by a party of geologists and biologists in March 1964. This report describes the topography, structure, current state of volcanic activity and general biological features of the archipelago. Detailed geological information will be published in *British Antarctic Survey Scientific Reports* Nos. 92 and 93, and botanical results in *Report* No. 94. The South Sandwich Islands group was discovered by Cook in 1775 and visited subsequently by Bellingshausen, several sealing parties, and a variety of twentieth century expeditions. The most detailed survey prior to 1964 was by the Discovery Investigations in 1931. Topographic mapping and geological and biological collections were, however, scanty until the study described in the present report. This study involved the establishment of a geologist, botanist and zoologist, with support of Royal Marines, for 16 days on Candlemas Island (chosen for its topographic, volcanic and biological diversity), and the examination of as many as possible of the other islands by a geologist, biologists and surveyors transported in H.M.S. *Protector* and landed by helicopter. The survey traverse measured distances by tellurometer along the greater part of the arc and revealed errors of up to 5 km. in the charted locations of some islands.

The South Sandwich Islands extend over a smaller distance than the Lesser Antilles, Mariana Islands or Kurile Islands, and the individual islands are also relatively small and separated by deeper water than in the Lesser Antilles. The deep-sea trench on the convex side of the arc descends to over 7,000 m. compared with 9,000 m. and 11,000 m. in the Puerto Rico and Mariana trenches, respectively. Like the Lesser Antilles, most of the South Sandwich Islands group exhibit recent or continuing activity, and a submerged cone at the north-west end of the arc appears to have been active in 1962, suggesting that the group may not have reached its full extent. Effusive volcanic activity, emitting basalts and basaltic andesites, predominates in contrast to the more explosive activity and dominance of two-pyroxene andesites and dacites in the Lesser Antilles.

Detailed accounts and sketch maps of all the islands are given, together with summary accounts of their vegetation and fauna. The 11 islands vary considerably in their height, size, complexity of structure, level of volcanicity and biological richness. Thule, Cook, Bristol, Montagu and Visokoi Islands are largely ice-covered, and Saunders and Candlemas Islands are more than half ice-covered. Bellingshausen, Vindication, Zavodovski and Leskov Islands, in contrast, are almost without ice caps. Zavodovski, Candlemas, Bellingshausen, Saunders, Bristol, Visokoi, Thule and Leskov Islands exhibit some degree of current or recent activity. Many islands appear to be simple volcanoes built about central vents, but Candlemas, Saunders, Montagu, Bristol and Cook Islands are more complex structures. Land vegetation is generally a sparse discontinuous assemblage of lichen and moss on cool ground, with the green alga *Prasiola* below bird colonies; around fumaroles emitting steam and hence providing a moist warm micro-climate there are, however, luxuriant moss and hepatic mats. The sea-bird fauna is typical of the maritime Antarctic, with large colonies of chinstrap penguins, lesser numbers of macaroni, Adélie and gentoo penguins, and abundant silver-grey fulmars, snow petrels and cape pigeons. There are several fur seal breeding colonies centred on Visokoi Island; elephant, leopard and Weddell seals also occur, the first of these in considerable numbers in summer.

CONTENTS

I. INTRODUCTION

THE South Sandwich Islands lie between lat. 56°18′ and 59°28′S., and long. 26°14′ and 28°11′W. (Fig. 1). There are 11 islands, of which ten form a curving chain extending about 386 km. from north to south, while the eleventh (Leskov Island) lies to the west of the arc near its northern end. Other volcanic peaks which fail to break surface are north-west from Zavodovski Island and possibly south-west from Cook Island. The island group forms the only typical volcanic arc in the Antarctic regions, and it is bounded by a deep-sea trench (greatest recorded depth of 4,518 fathoms [8,265 m.]) along its convex eastern side.

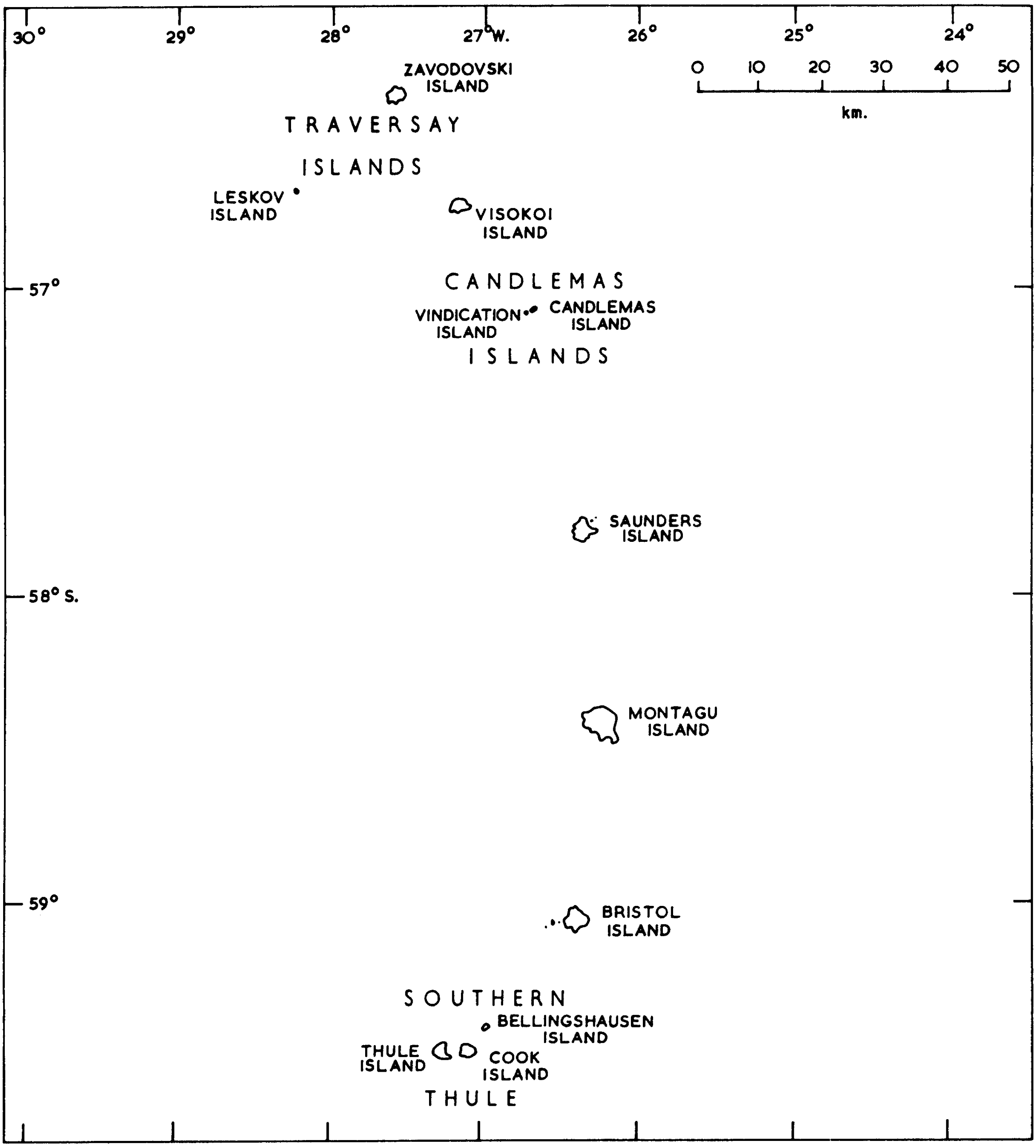


FIGURE 1
Sketch map of the South Sandwich Islands.

Although the eight southern islands were discovered by Cook in 1775, and the three northern ones by Bellingshausen in 1819, the first detailed survey of the group was not made until February 1930, when R.R.S. *Discovery II* spent 3 weeks in the area (Kemp and Nelson, 1931). The work of this expedition was hampered by bad weather and heavy swell and, apart from one landing on Thule Island, all information was gained from the ship during close circumnavigation of the islands. Subsequent visits, which are reviewed below, culminated in brief examinations by scientists from R.R.S. *Shackleton* in 1961 and H.M.S. *Protector* in 1962. These visits made it evident that there was still much to be done in the island group, and that *Protector* with her two helicopters was an ideal vessel from which to mount a detailed study. The helicopters could often land when boat operations were impossible. Consequently, in March 1964 this ship spent 3 weeks in the South Sandwich Islands, transporting teams of geologists, biologists and surveyors from point to point and making sounding runs offshore. A preliminary report of this survey has already been published (Baker and others, 1964). The present report is the first of a series describing the results of that study. It is concerned with the organization and itinerary of the operation; it outlines the collections made and contains accounts of the topography of the individual islands and a general discussion of the island group as a whole. The geological structure of the islands is considered together with their volcanic history and current activity. A brief account is given of the climate, vegetation and fauna. The report as a whole is planned as a replacement for the *Discovery Report* by Kemp and Nelson (1931), and new maps of the islands are included.

Three other *British Antarctic Survey Scientific Reports* give details of the results of this study. These deal respectively with the geology and petrology of Candlemas Island (No. 92, by J. F. Tomblin), the geochemistry of the South Sandwich Islands (No. 93, by P. E. Baker) and the botany of the archipelago (No. 94, by R. E. Longton and M. W. Holdgate). Other scientific information that has either been published already elsewhere or is insufficient in quantity to justify a separate paper is included in the present report. The notes on birds and seals, included in the accounts of the various islands and summarized in the biological section of the discussion, are based on observations by all members of the team, but especially R. W. Vaughan. P. J. Tilbrook has provided the account of the terrestrial invertebrate animals collected by him on Candlemas Island and by M. W. Holdgate in other parts of the archipelago, and largely described in previous papers. Lt Cdr C. J. C. Wynne-Edwards, R.N. was responsible for survey operations and has contributed the text describing these, and Instructor Lt M. J. Cuming, R.N. made the meteorological observations summarized on p. 13–14.

II. HISTORY OF EXPLORATION OF THE SOUTH SANDWICH ISLANDS

A. Visits to the Islands

On 31 January 1775, a seaman named Freezeland aboard H.M.S. *Resolution* commanded by Capt. James Cook, R.N. sighted for the first time the rocky island which now bears his name (Cook, 1777). As the fog lifted a little and the vessel neared the land, Cook was able to make out the three high rocks off the western end of Bristol Island with the ice-covered coast of the main island behind them. He named the land "Cape Bristol", thinking it to be a headland of a larger mass, and, sighting the peaks of the islands to southward at the same time, named them "Southern Thule" because they were at that time the southernmost land to be discovered. Cook was unable to close the land because of the danger of being caught on so savage and ice-encumbered a lee shore, and consequently could not determine the true extent and insular nature of his discovery. Passing northward, he sighted another point of land which he named "Cape Montagu", considering it to be a promontory because he thought he saw land between it and "Cape Bristol". However, he was in no doubt as to the insular nature of Saunders Island, discovered on 1 February 1775, and Candlemas and Vindication Islands, found on the following day. Because the weather was hazy and he could not approach close to the land, Cook was unable to give very detailed descriptions of these islands and failed to report their volcanic nature, but he determined their positions with an accuracy remarkable for the period. After sighting and naming "the Candlemas Islands", he resumed his voyage to the east and so did not discover the three northern members of the island group.

On 22 December 1819, the Imperial Russian Expedition in the corvettes *Vostok* and *Mirny*, under Capt.

T. von Bellingshausen, sighted a small rocky island which they named "Lyeskov Island" after the first lieutenant of *Vostok* (Bellingshausen, 1945). Bellingshausen's artist, Mikhaylov, drew the island with great accuracy and this drawing with the brief description supplied is sufficient to establish that there has been no major change in the aspect of the island since its discovery. On 23 December 1819, Visokoi Island was discovered and drawn, again in its present form, and on 24 December a visit was made to Zavodovski Island which had attracted attention by its dark smoke plume. A good drawing of this island is of interest in suggesting activity at the time from a fissure on the north-west side of the cone, while Bellingshausen's account confirms the existence of a main crater on the south-west side near its present position. A party landed and found many chinstrap and some macaroni penguins incubating eggs, and they collected rock and bird specimens. Passing southward along the island group, useful drawings and notes were made at the southern islands, and the insular nature of Bristol and Montagu Islands, and the Southern Thule island group was established. The drawings of Saunders Island are of interest in suggesting topographic changes since 1819, which are discussed on p. 39–42. In the Southern Thule group, Bellingshausen demonstrated the presence of three islands and named the largest after Cook.

Benjamin Morrell, a sealer of Stonington, in *Wasp*, with another sealer *Henry* in company, visited the islands on 28 February 1823. His account (Morrell, 1832) has always been treated with reserve, and it tallies imperfectly with other descriptions of the islands, in whose vicinity he claimed to have seen numerous birds resembling birds of paradise. However, his account of "two burning volcanoes" in the Candlemas Islands group may refer to considerable activity in the northern part of the present large island, and his report of good shelter in the north-east part of Thule Island, presumably in Douglas Strait off the beach which curves out to Beach Point, is reasonable. Morrell's account is remarkable in that he stated that he discovered no fur seals at all in the islands and only saw about 44 elephant seals and 50 "sea dogs" (Weddell seals?). A similar lack of success may have been met with by Capt. J. Brown in the schooner *Pacific*, who re-discovered Leskov, Visokoi and Zavodovski Islands in December 1830 (Fanning, 1834). Not knowing of Bellingshausen's visit, Brown named these islands "Potter's Island", "Willey's Island" and "Prince's Island", respectively; useful descriptions were given of all of them and these are discussed on p. 14–28. Brown landed on Zavodovski Island on 12 December 1830 and he noted the fauna; since he did not move on to Visokoi Island until 22 December, it is tempting to conclude that he did in fact meet with some fur seals about whose presence he felt it wise to keep silent. No landings were made elsewhere in the island group, although *Pacific* went as far south as Saunders Island (which was re-named "Christmas Island"). At the same time that Brown was in the northern part of the island group, John Biscoe, in *Tula* and *Lively*, was visiting Montagu Island where a landing seems to have been made on 22 December 1830 (Biscoe, 1830). No seals were reported.

Although there are thus three reports of visits to the island group by sealing vessels in the years between 1823 and 1830, none records that any animals were killed. Yet it seems most probable that fur seals bred on these islands in this period, since they certainly do so today and since a total harvest of over 6,000 skins was obtained during the latter part of the nineteenth century. In general, the second peak period of Antarctic sealing around 1870–90 was less productive than the first devastating exploitation of the newly discovered colonies between 1800 and 1830, and in the South Shetland Islands only about 45,000 skins were obtained in the later period, compared with 320,000 in the two years 1820 and 1821 alone (Bonner, 1968). There seems reason to deduce, therefore, that unrecorded visits may have been paid to the South Sandwich Islands by sealers in the early nineteenth century.

In 1875–76, during the recovery of Antarctic sealing, a vessel, probably *Franklin* of New London under Capt. J. W. Buddington, took about 2,000 seals at the three northern islands (Allen, 1899). In the next season, 1876–77, six ships including *Franklin* took 4,000 seals in the island group and thereafter, although sealers visited the islands in 1877–78, 1880–81 and 1891–92, only a total of under 500 was obtained, the 1880–81 season proving completely blank. It may well be that it was at this period that the spars, blubber hook and other debris seen on Candlemas Island in 1964 were brought ashore, and this period of intensive sealing also probably explains why C. A. Larsen, who explored the islands in 1908, failed to find fur seals at all.

Larsen (1908) was in the island group in *Undine* from 5 to 21 November 1908, landing on Zavodovski, Candlemas, Saunders, Montagu and Bristol Islands, and making notes on birds and collecting rock specimens. Unfortunately, probably owing to illness following exposure to sulphurous fumes on Zavodovski Island, Larsen's description is often imprecise and his sketch maps are completely unreliable. Where useful, these data are discussed in the sections dealing with individual islands (p. 14–54). In 1911, the German South Polar Expedition in *Deutschland*, under Filchner (1923), sighted Leskov, Visokoi, Zavodovski and Candlemas Islands, and useful information was obtained about the first-named, including the suggestion of volcanic activity from the summit ridge, which was confirmed in 1964. In the same year, a whaling expedition in the catcher *Thulla* and barque *Havfruen*, under Capt. Ole Jörgensen, visited the eight southern islands and landed in Ferguson Bay, Thule Island. *Endurance*, under Sir Ernest Shackleton passed through the island group in 1914, and in 1922 R.Y.S. *Quest*, then under the command of Cdr F. Wild, spent some time examining Zavodovski Island. A running survey made by Cdr F. A. Worsley gave a very accurate representation of the south-west and east coasts of this island (Douglas and Campbell Smith, 1930), and notes were made during boat journeys close inshore.

A second whaling expedition in the catcher *Busen VII*, under Capt. H. Hansen, visited the islands in January 1927 (Kemp and Nelson, 1931). The islands north of Saunders Island were examined, the volcanic activity of the latter peak, first noted by Bellingshausen, being confirmed. In 1927–28, the whaling factory ship *Anglo-Norse* worked about the islands, with a biologist, J. E. Hamilton of the Discovery Investigations' staff aboard. Activity from the summit of Visokoi Island was recorded in this summer and Bristol, Montagu and Thule Islands were visited. The islands were also visited by whaling fleets in 1928–29 and 1929–30, and numerous sightings must have been made.

On 26 February 1930, R.R.S. *Discovery II*, with Capt. W. M. Carey in command and S. Kemp as senior scientist, arrived off Zavodovski Island. From that date until 17 March the ship worked constantly about the islands, circumnavigating them close inshore, making running surveys of the coasts, sounding in the adjacent waters, and obtaining numerous photographs, sketches and notes on the appearance of the rocks and of birds and seals seen at sea and ashore. It is unfortunate that only one landing, on Thule Island, could be made in this period so that information about the land vegetation, rock and plant collections, and data about birds definitely resident in the island group, were largely unobtainable. Even with this limitation, however, the work of *Discovery II* is remarkable for providing so comprehensive a picture of the region. The monograph by Kemp and Nelson (1931) has, up to the time of the present report, been the only extensive account of the islands available, and it has been in continual use during the preparation of this report.

In 1935, an eruption at Bristol Island, which had hitherto been thought extinct, was observed from the whaling vessel *Sourabaya* (Admiralty, 1948). In 1937, R.R.S. *William Scoresby*, the second of the Discovery Investigations' ships, visited Saunders Island and G. W. Rayner, senior scientist aboard, landed and obtained rock specimens which were later described by Tyrrell (1945). There is no record of any visit during the 1939–45 war but in 1949, when whaling had been resumed, *Slava 15* (under A. N. Solyanik) was in the area and made observations and sketches (Tikhonov, 1952). *Discovery II* returned in 1950–51, passing through the islands during a circumpolar cruise, and in 1951–52 an Argentine expedition under the command of E. L. Diaz, in *Hercules* and accompanied by *Sarandi*, visited the islands and made the first recorded landing on Vindication Island (Secretaria de Marina, 1958). In 1953–54, R.R.S. *John Biscoe* (under Capt. W. Johnston) visited the northern islands, and in 1954–55 the Argentine ice-breaker *General San Martín* (Capt. A. Ogara and A. C. Lopez de Bertodano) landed a party which built the refuge hut "Tentiente Esquivel" at Hewison Point, Thule Island. This hut was occupied in the 1954–55 summer and again in 1955–56, the personnel being evacuated on 14 January 1956 by *General San Martín* 3 days after they had witnessed a violent eruption on Bristol Island (Secretaria de Marina, 1958). The Argentine expeditions in these two seasons also undertook photography and hydrographic survey around several of the islands, and one result of their work was the improvement, on Argentine Chart 111 (Islas Sandwich del Sur, 1953, corrections to 1956) of the coastline of Zavodovski Island. The coastline of Candlemas Island was also modified on this chart, the headlands of Carbon Point and Clapmatch Point being shown; Cook Island was altered less usefully and an inset of part of Cordelia Bay, Saunders Island, was provided.

Since 1956, British, Argentine, Soviet and United States ships have visited the islands periodically. In 1956, M.V. *Theron* (Capt. H. Marø) called at Thule Island on her way south, and in the same year *Protector* paid two visits to the island group, investigating most of the islands from Thule Island northward and landing on Vindication, Visokoi and Thule Islands. Ornithological records made during these two visits were published by Wilkinson (1956, 1957). *General San Martín* paid a routine visit in the 1956–57 season, and on 20 January 1957 the Soviet whaler, *Slava 15* (under A. N. Solyanik), landed a party on Montagu Island (Ivanov, 1959*a*). The same Russian vessel visited Zavodovski Island on 16 December 1957 when a party landed by boat and walked some way inland (Ivanov, 1959*b*), erecting a cairn as a mark of their visit. Ivanov's two papers include useful information and record that some collections were made on both occasions. In 1957–58, *General San Martin* (under Capt. A. Patron Laplacette) again called at the islands, landing on Zavodovski Island, and in 1960 *Protector* (under Capt. D. Forbes) visited Visokoi Island and found for the first time the fur-seal colony at Irving Point, of which photographs were obtained (O'Gorman, 1961).

In January 1961, an extremely important brief visit to the South Sandwich Islands group was made by *Shackleton* under Capt. D. H. Turnbull (1961*a*, *b*). Favoured by unusually calm weather, landings were made on more islands than had ever before been achieved in the course of a single visit. At Zavodovski Island, a boat was brought inshore at two points and astronomical observations were made by theodolite (sun sights); rocks and algae were collected and gravity readings were made. At Visokoi Island, a landing was made at Finger Point and gravity readings were again taken, while rocks, lichens, algae and mosses were collected. Further plant collections were made at Candlemas Island, where a party was landed by boat in Seaserpent Cove; the material included the grass *Deschampsia antarctica*, which was not hitherto known from the islands. At Vindication Island, a boat landing was made near Chinstrap Point and at Crosscut Point, and mosses and rock specimens were collected. A landing on the south-west coast of Saunders Island was made in a lead sheltered by an ice belt offshore, and finally a party of three men got ashore at Leskov Island, on a narrow ledge near Rudder Point.

This useful visit was supplemented in March 1962 by a 2 day examination of the islands from *Protector* (Capt. R. H. Graham). Landings were made by helicopter at Hewison Point, Thule Island, on the south side of Bellingshausen Island, on the north-east of Saunders Island, between the two lagoons of Candlemas Island and on the eastern slopes of Vindication Island. Collections of rocks and plants were made in all these places. In addition, air photographs were obtained of all these islands and of Visokoi, Zavodovski and Cook Islands, and these, together with Bristol Island, were inspected from the air. A detailed account of this inspection and of the principal new observations made has been given by Holdgate (1963), while Gass and others (1963) have described the rafts of pumice emitted from a submarine eruption which occurred at that time.

These two visits by *Shackleton* and *Protector* directly inspired the investigation described in this report. In the 1962–63 season, however, there were two further visits to these islands. U.S.N.S. *Eltanin* spent a period among the islands and a party approached by boat close to Freezland Rock, but they were unable to land (personal communication from W. Seelig). On 14 and 15 February 1963, *Protector* (under Capt. R. H. Graham) surveyed the shoal which is believed to be the submerged cone from which the floating pumice found in 1962 was emitted. A chart of this submarine cone, which rises to within 16 fathoms [30 m.] of the surface, was prepared by Lt B. N. Wilson and it is discussed on p. 68–69. This is the latest recorded visit to the group before 5 March 1964 when *Protector* (under Capt. M. S. Ollivant) arrived to commence the survey described in the present report.

B. Scientific Information and Collections

1. *Topographic survey*

Determinations of the positions of the islands have been made by most visiting expeditions, and it was discrepancies between these, especially emphasized in reports by Turnbull (1961*b*) and Mackendrick (1962) which led to the decision to attempt a survey traverse with accurate, shore-based astronomical observations in the present survey.

The first maps of the islands, after rough coastline depictions by Cook and Bellingshausen, were the rough sketch charts by Larsen (1908). These do not stand up to close scrutiny and, apart from a reasonably good running survey of Zavodovski Island by Worsley (Douglas and Campbell Smith, 1930), no accurate mapping was undertaken until the survey by *Discovery II* in 1930 (Kemp and Nelson, 1931). The resulting charts depict coastlines only; no attempt was made to indicate inland form lines. Thereafter nothing was done until the 1953–56 period, when some amendments were submitted and incorporated in British charts, and radar-screen records and photographs by Argentine parties led to modification of the coastlines of some islands on Argentine charts. Manuscript corrections of coastlines were made on a chart by Lt D. Mackendrick following *Protector*'s visit in March 1962, while notes on chart discrepancies were also submitted by Capt. D. H. Turnbull after *Shackleton*'s visit. These comments, together with those by

Holdgate (1963), supplemented by the need to map inland topography as a base for scientific field study, led to the inclusion of as much detailed recording of terrain as possible in the present study.

2. *Geology*

Rock collections were made on Zavodovski, Candlemas, Saunders, Montagu and Bristol Islands by Larsen in 1908 and these were described by Baeckstrom (1915). Further samples were dredged from near Zavodovski Island by R.Y.S. *Quest* in 1922 and they were commented on by Douglas and Campbell Smith (1930). In 1930, a party from *Discovery II* collected 15 specimens from the scarp at Beach Point, Thule Island, and these were described in detail by Tyrrell (1931). Further material was collected at Saunders Island by G. W. Rayner from *William Scoresby* in 1937, and these rocks have been described by Tyrrell (1945). According to Ivanov (1959*a*, *b*), rock samples were taken from both Montagu and Zavodovski Islands by men from the Soviet ship *Slava 15* in 1956, but the whereabouts of these samples is not clear. It is almost certain that collections were also made in the same period by men of the Argentine parties at Thule Island. However, it was not until the visit of *Shackleton* in 1961 that a major rock collection was attempted. The resulting samples have been incorporated for study with those obtained during the 1964 survey, as have those obtained by Holdgate (1963) at Thule, Bellingshausen, Vindication, Candlemas and Saunders Islands.

The rocks collected by Larsen are now housed in the Department of Geology, University of Uppsala, Sweden, whereas those obtained by *Discovery II* and *William Scoresby* and studied by Tyrrell (1931, 1945) are in the Hunterian Museum, Department of Geology, University of Glasgow. The specimens obtained by *Shackleton* in 1961, by *Protector* in 1962 and during the present study are in the British Antarctic Survey collections at Cambridge.

3. *Geophysics*

Magnetometer traverses in the vicinity of the island group were made by *Shackleton* in 1961 and by *Eltanin* in 1962–63. Gravimeter readings were taken on Zavodovski, Leskov, Visokoi, Vindication, Candlemas and Saunders Islands during landings from *Shackleton* in 1961. Recent geophysical studies in the Scotia arc (Griffiths and others, 1964) include a few magnetic traverses and gravity measurements in the northern part of the South Sandwich Islands group.

4. *Botany*

The first plant material to be collected in the South Sandwich Islands was a sample of the green alga, *Prasiola crispa*, which was obtained at Beach Point, Thule Island, by a party from *Discovery II* (Kemp and Nelson, 1931). The same authors recorded observing lichens and the algae of "red snow" on several islands, but they were not able to obtain specimens. In 1957, a party from *Slava 15* collected *Prasiola*, lichens and algae cast up on the beach at Montagu Island (Ivanov, 1959*a*), and at Zavodovski Island (Ivanov, 1959*b*). The whereabouts of this material is uncertain. A more extensive collection was made by P. Kennett and H. A. D. Cameron from *Shackleton* in 1961; this included *Prasiola* from Visokoi and Zavodovski Islands, lichens from Candlemas and Visokoi Islands, mosses from Visokoi, Candlemas and Vindication Islands, and the grass *Deschampsia antarctica* from Candlemas Island. The collecting localities for these samples, and the serial numbers allocated to them, have been tabulated by Holdgate (1963), and the collections have been merged with those from the 1964 survey for discussion in *British Antarctic Survey Scientific Report* No. 94 by R. E. Longton and M. W. Holdgate. The plants collected by Holdgate from *Protector* in 1962, including *Prasiola* from Thule Island, lichens from Thule, Bellingshausen, Saunders, Vindication and Candlemas Islands, hepatics from Bellingshausen and Candlemas Islands, and mosses from Bellingshausen, Saunders, Vindication and Candlemas Islands, have also been incorporated with the later collections. Some information, especially about the vegetation of ground warmed by volcanic heat, has been published in a general discussion of the temperature relationships of Antarctic plants by Longton and Holdgate (1967).

The sample of *Prasiola* collected from *Discovery II* in 1930 is housed in the British Museum (Nat. Hist.). The material obtained from *Shackleton* in 1961, from *Protector* by Holdgate in 1962 and during the present study is at present housed in the British Antarctic Survey herbarium at the Institute of Terrestrial Ecology, Bush Estate, Penicuik, Midlothian, Scotland.

5. *Zoology*

Marine zoological collections were made in the vicinity of the South Sandwich Islands by Larsen in 1908 (Richardson, 1911), and from *Quest* in 1922. During the survey of the island group in 1930, *Discovery II* dredged, took plankton hauls and caught some fish. The dredgings yielded in most places large hauls of ascidians (*Ascopera* and other genera), while the few fishes caught by lining and trawling included *Notothenia rossii, N. angustifrons* and *Parachaenichthys georgianus* (Kemp and Nelson, 1931). Further collections of marine fauna were made by *William Scoresby* in 1937 and by *Discovery II* in 1952, while *Eltanin* also collected plankton in the vicinity of the South Sandwich Islands in 1962–63.

In 1930, the party from *Discovery II* who landed at Beach Point, Thule Island, collected one collembolan and two mites. Collembola and mites were also taken at Hewison Point, Thule Island, by Holdgate in 1962. Bird specimens were taken on Zavodovski Island by Bellingshausen in 1819 but there is no other record of bird or mammal collections prior to the 1964 survey.

The marine specimens obtained by Larsen in 1908 are probably in the Museo Nacional de Historia Natural, Buenos Aires. The *Discovery II* marine material and that obtained by *Quest* is housed in the British Museum (Nat. Hist.). Accounts of these last two collections have been published in *Discovery Reports* dealing with the appropriate taxonomic groups. Collembola and mites obtained by *Discovery II* in 1930 are also in the British Museum (Nat. Hist.), while the few specimens obtained in 1962 were handed to J. L. Gressitt of the Bernice P. Bishop Museum, Honolulu, Hawaii. Details of these collections have already been published by Tilbrook (1967*a*, *b*).

III. THE 1964 SURVEY OF THE SOUTH SANDWICH ISLANDS

A. Programme and Personnel

The survey of the South Sandwich Islands planned for March 1964 had the following main aims:

Survey

- i. To locate the islands accurately by shore-based astronomical sights, ideally comprising at least two full sets of star sights at widely spaced points in the group, together with other sun and star observations for azimuth.
- ii. To fix the relative positions of all the islands by a hydrodist (tellurometer) traverse and observation of angles by theodolite, thus linking the islands to one another and determining their absolute geographical positions by reference to the astronomical observations.
- iii. To carry out triangulation schemes on as many islands as possible, as a means of controlling air photographs and so allowing maps to be made for the scientific programmes.
- iv. To obtain vertical and oblique air photographs of as much ground as possible.
- v. To record the coastlines of the islands by photography of p.p.i. screens.
- vi. To determine the submarine topography around the islands by carrying out sounding runs whenever opportunity offered.

Climatology

To carry out a regular programme of meteorological observations throughout the period spent among the islands.

Geology

- i. To make a detailed study of Candlemas Island, by establishing one geologist in camp there for the full period of the survey. This man would make a geological sketch map of the island and obtain comprehensive collections and notes. Candlemas Island was selected for detailed study because its northern part is well exposed and exhibits a variety of recent volcanic features.
- ii. To study the structure of the other islands by transporting a second geologist by helicopter to as many points as possible, and by allowing him to make observation flights around those areas on which landing was impossible. Rock collections would be made in the course of this programme,

from all possible points, for subsequent petrological studies and comparison with those from Candlemas Island. The programme of air photography was aimed also towards enlarging geological knowledge.

Glaciology

Measurements of ice temperature in relation to depth were required on Candlemas Island and it was proposed to establish stakes whose future movement could be followed.

Botany

i. To make a detailed study of the vegetation and flora of Candlemas Island by establishing one man in camp there for the period of the survey, to map vegetation, study thermal and vegetational gradients about fumaroles, and collect a comprehensive series of specimens.
ii. To make general collections and notes on vegetation from as many other islands as possible, by transporting a second botanist widely by helicopter.

Zoology

i. To make a detailed study of the land invertebrate and vertebrate fauna of Candlemas Island, by establishing one zoologist in camp there. This man would be equipped with apparatus for the extraction of soil fauna, which he would sample regularly on a quantitative basis. He would also make a census of sea birds and seals on the island and obtain general animal ecological information.
ii. To undertake parallel sampling of the soil fauna from as many other points in the island group as possible, and to make notes on, and counts of, the birds and seals of those islands.
iii. To make a census of the fur seal populations of the South Sandwich Islands and to locate the main breeding grounds of this species.

In accordance with this plan, the investigation involved two main scientific parties. The Candlemas Island party, consisting of one botanist, one zoologist and one geologist, together with a naval radio supervisor and four Royal Marines support personnel, was established in camp on the second day of the programmes and relieved 2 days before *Protector* left the island group. As an ancillary task, the Royal Marines support group undertook some glaciological studies. The ship party comprised one geologist, one biologist concerned with vegetation and soil fauna, and one zoologist concerned with birds and seals, and especially qualified to undertake a census of fur seals. This party remained in *Protector* most of the time, spending only occasional nights in camp ashore, and succeeded in landing on most of the islands. In addition to these two scientific parties, two survey parties were based in *Protector*, landing by helicopter at appropriate points for tellurometer traverse stations and camping overnight at points appropriate for astronomical observations. Royal Marine support personnel were attached to all parties as required.

The scientific and survey personnel were as follows:

Candlemas Island party

Zoologist: P. J. Tilbrook (leader of party)
Botanist: Dr. R. E. Longton
Geologist: J. F. Tomblin

Ship scientific party

Biologist (studying vegetation and soil fauna): Dr. M. W. Holdgate (also senior scientist of the project)
Zoologist: R. W. Vaughan
Geologist: Dr. P. E. Baker

Survey parties

Hydrographic Officer in charge: Lt-Cdr C. J. C. Wynne-Edwards, R.N.
Assistant surveyor: Lt D. Fulton, R.N.
Assistant: Midshipman A. H. Morrow, R.N.

In addition to these three shore-going parties, the recording of meteorological data aboard *Protector* was the responsibility of Instructor-Lt M. Cuming, B.Sc., R.N., while the Navigating Officer, Lt B. N. Wilson, R.N., undertook the plotting of soundings and supervised the photography of radar screens. Photography from the two Whirlwind Mark I helicopters of the ship's flight was supervised by Lt D. Dobson, R.N. Throughout the operation a film record was maintained, both aboard and ashore, by Mr. C. Lagus of the British Broadcasting Corporation, who accompanied various survey and scientific parties.

The movement of shore parties from point to point was entirely effected by *Protector*'s ship's flight, commanded by Lt J. Leeson, R.N. He, together with the other pilots, Lt A. Mathias, R.N. and the First Lieutenant of *Protector* Lt-Cdr A. Crosse, R.N., bore the brunt of much of the logistic effort under difficult conditions. Finally, the organization of day-to-day activities, with the integration of the various programmes, devolved in large measure upon the Captain of *Protector*, Captain M. S. Ollivant, M.B.E., D.S.C., R.N., who was in command of the operation.

B. Itinerary and Project Diary

A detailed record of the programme with the main activities by ship, helicopters, scientific parties and survey parties is given in Table I. It will be apparent that the main objectives of the operation were achieved. The camp on Candlemas Island with its three scientific staff and support personnel was established on 6 March 1964 and remained in occupation until 22 March. Meanwhile, the ship-borne party of three scientists was able to visit all of the islands in the group except for Zavodovski Island, and the survey parties were able to complete their traverse from island to island from the Southern Thule group as far north as Visokoi Island.

The early part of the project was a period of intense activity and rapid movement of parties by helicopter, often under marginal conditions. In contrast, the final week was largely spent in enforced inactivity, due not to the violent storms which had been expected but to persistent fog. As a result, it proved impossible to examine Zavodovski Island, which had been provisionally allocated 2 days for study, or to re-visit Leskov Island as had been hoped. These islands will undoubtedly repay further examination but, even with their omission, the programme was successful in allowing a general picture to be gained of the South Sandwich Islands and of their structure and biology.

C. Survey Operations

The general aims of the survey operation are described on p. 9. In setting out these broad terms of reference, it was recognized that previous surveying attempts in this region (in particular those of *Discovery II* in 1930) had been severely hampered by inclement weather and poor visibility; at no time had it been possible to observe for astronomical position ashore.

A list of survey priorities was drawn up and maximum importance was attached to the determination of the geodetic position of the island group as a whole and the relative geographical positions of the islands. With the limited time available and the small number of trained personnel, this project itself might well have occupied the entire period of the visit. Every effort was made in the field to improve the existing topographic maps, resulting from the surveys of *Discovery II* in 1930, by local triangulation, vertical and oblique air photography, and by personal observation. Whilst survey parties were ashore, it was planned that the ship should carry out soundings using a recording echo sounder. Using an available fixing method (usually radar and gyro-compass bearing), these soundings could then be related to some identifiable feature ashore. The southward reconnaissance on 5 and 6 March provided an excellent opportunity for selecting sites for the subsequent survey traverse. In the South Sandwich Islands group it is very difficult to find satisfactory stations that are both accessible and intervisible; if they are to be on rock, it is in most cases necessary for them to be near the coast. Ideally, a traverse should close but, in this crescent-shaped island group, it was planned to make astronomical observations at either end of the group which could then be linked by means of the distances obtained by tellurometer.

On 8 March 1964, a landing was made on Bellingshausen Island and a survey station was established on Basilisk Peak, the summit of the island. Perched on the lip of the crater, it provided all-round visibility, including to the west a view of Cook Island and the northern edge of Thule Island, to the north Bristol Island and the offlying Freezland, Grindle and Wilson Rocks.

3 days were spent in the Southern Thule group and, although the sun appeared fitfully on two of these days, the sky remained overcast every night and no star observations were made. Two sun azimuths were observed from the Bellingshausen Island station. *Protector*'s helicopters ferried the two survey parties around the Southern Thule group during this period and the three islands were linked by distance measurements and angles. A small internal triangulation of Bellingshausen Island was also carried out; the stations were first marked on the ground and vertical air photographs were subsequently taken from the helicopters.

On 12 March, the master tellurometer party was transported to the islets off the west coast of Bristol Island; fierce down-draughts had precluded the possibility of landing on the nearby mainland but in any case there appeared to be no suitable sites for survey stations on either the west or east coast of the island. After an unsuccessful attempt to land on the summit of Grindle Rock, a landing was eventually made with some difficulty on the south side of Freezland Rock where a station was established about 10 m. from the shore and about 3 m. above sea-level. Although intervisible with the Bellingshausen Island station, it was not wholly suitable for tellurometer measurement even though a calm sea, relatively free from icebergs, permitted a clear "sighting" path. During this and all subsequent tellurometer observations at least six sets of readings were made; when time allowed, 12 sets of readings were made.

The station established on Freezland Rock was not intervisible with Montagu Island to the north. However, the peak of Freezland Rock was intervisible and an estimate was made of the distance between the station and the summit of Freezland Rock; in doing this, an additional error may have been introduced but no other method was practicable in the time available. From Freezland Rock, the link was made to Allen Point at the south-eastern extremity of Montagu Island; here, as in subsequent stations, the observation point was marked by a cairn and its position recorded in terms of the local topography.

For the distance measurement between Freezland Rock and Allen Point, a landing on Freezland Rock was impracticable and this leg was measured by carrying the master tellurometer airborne from one of *Protector*'s helicopters hovering over the rock. This system had been used previously and, although it is not nearly as accurate as using two fixed stations on the ground, it is nevertheless capable of giving fairly useful results. Unfortunately, on the day the measurement was made, intermittent snow storms affected the path between the two instruments and seriously reduced the signal strength. Consequently, no great accuracy can be attached to this leg of the traverse and it must be regarded as a weak link with an error of ± 500 m.

Because of the curvature of the South Sandwich Islands group, Saunders Island is not visible from Allen Point. Two further stations were therefore established on the east coast of Montagu Island, one on a rocky promontory about 1·5 km. north of Allen Point and a second on the glacier a further 8 km. northward. The ice station cannot be recovered but no other site would have fulfilled the purpose of establishing this essential link in the traverse. Whilst on Montagu Island, further azimuths and one position line were also obtained.

On the morning of 16 March, the second longest distance of the traverse (69 km.) was measured between the north-eastern station on Montagu Island and a good rock station on Nattriss Point, the south-east promontory of Saunders Island. The same afternoon, in good weather, a second station was established on Saunders Island at Yellowstone Crags in the north-east, and a further distance was measured to these. That night, camp was made nearby and the theodolite set up for star observations but once again the sky remained overcast. Next morning, however, a further set of azimuth observations was made by means of the sun.

Taking advantage of good weather on the following day (17 March), the remote tellurometer party was landed on the eastern side of the summit of Vindication Island and a satisfactory measurement was obtained for the distance to Saunders Island (75·5 km.). In all cases where distance was measured, angles were also observed but on the longer rays, such as this, positive sighting was dependent on identification of distinguishing local features as described by the occupants of the station over the radio. Although the possibility of using a heliograph was considered, it would have been most unsatisfactory in view of the infrequent appearance of the sun.

On the afternoon of 17 March, the master tellurometer party was transferred to the main camp on Candlemas Island and the distance was measured from there to Vindication Island. Plans were made for a limited triangulation of Candlemas Island, because a reasonable map seemed desirable in view of the geological and biological work that was being carried out on the island.

Several star observations were made during the night of 17–18 March but these were incomplete owing to heavy cloud cover. However, a sufficient number of sightings was obtained for a reasonable calculation of

TABLE I

PROJECT DIARY

March 1964 Date Day Time	Weather	Ship	Helicopters	Scientific parties	Survey parties
5 Thurs. p.m.	Clear; fresh south-westerly wind	Sounding between Leskov and Candlemas Islands	Complete vertical and oblique air photography of Leskov Island	Holdgate, Baker, Longton and Tomblin—3 hr. study of Leskov Island. Geological and biological collections	Wynne-Edwards on Leskov Island. Measured angles to Visokoi and Zavodovski Islands
6 Fri. a.m.	Clear with snow showers; fresh south-westerly wind	Sounding between Candlemas and Saunders Islands	In support of scientific and survey parties	Holdgate and Tilbrook—to Candlemas Island; selected camp site	Wynne-Edwards to Candlemas Island. Search for site for tide pole; found impracticable
				Tilbrook, Tomblin, Longton and support party—established camp on Candlemas Island for 2 week stay	
			Aerial inspection of Candlemas and Vindication Islands	Baker—in helicopter over Candlemas and Vindication Islands	
p.m.	Clear with snow showers; fresh south-westerly wind	Sounding east and south from Saunders Island	Conveying scientific and survey party at Saunders Island	Baker—aerial inspection of Saunders Island (Nattriss Point and Cordelia Bay)	Wynne-Edwards—aerial inspection of Cordelia Bay, Saunders Island. No site found for tide pole
7 Sat. a.m.	Fresh westerly wind. Good visibility	Sounding around Montagu Island and towards Bristol Island	Conveying shore parties	Baker, Vaughan and Lagus—to Montagu Island (Allen Point and beach on south of island). General observation and collection	Wynne-Edwards—to Montagu Island (Allen Point). Angles and sun lines obtained
p.m.	Fresh westerly wind. Good visibility	Sounding west of Bristol Island and towards Southern Thule group. Radar photographs	Carrying scientific and survey party	Baker—Bristol Island; aerial inspection	Wynne-Edwards—to Bristol Island; aerial inspection
				Baker and Holdgate—to Freezland Rock. Geological and biological survey and collections made	
8 Sun. a.m.	Moderate south-westerly winds; moderate visibility	Sounding around Southern Thule group	Establishing shore parties and moving survey stations	Holdgate, Baker, Vaughan, Lagus and support party—to Bellingshausen Island. Aerial inspection followed by establishment of camp for 3 day geological and biological programme	Wynne-Edwards and Morrow—aerial examination and establishment in camp on Bellingshausen Island
					Fulton—to Thule Island (Beach Point). Hydrodist link to Bellingshausen Island
p.m.	Moderate south-westerly winds; moderate visibility	Sounding around Southern Thule group	Moving survey party	Survey of Bellingshausen Island in progress	Fulton—to Cook Island (Resolution Point). Hydrodist link to Bellingshausen Island
9 Mon. a.m. p.m.	Overcast with variable south-westerly winds and some snow showers; poor visibility	Sounding over shoal east of Bellingshausen Island	Moving survey party	Survey of Bellingshausen Island in progress	Fulton—to Bellingshausen Island. Worked with Wynne-Edwards on local triangulation
10 Tues. a.m.	Moderate south-westerly winds; variable visibility	Sounding in Southern Thule area		Survey of Bellingshausen Island in progress	Local triangulation on Bellingshausen Island in progress
p.m.	Moderate south-westerly winds; variable visibility	Sounding in Southern Thule area	Obtained vertical and oblique air photographs of Bellingshausen Island	Survey of Bellingshausen Island concluded	Local triangulation on Bellingshausen Island concluded
			Lifted off shore parties in evening	Holdgate, Baker, Vaughan, Lagus and support party return to ship	Wynne-Edwards, Fulton, Morrow and support party return to ship
11 Wed. a.m.	Fresh and increasing south-westerly winds	Sounding around Southern Thule group	Transported survey and scientific parties. Oblique air photographs of Thule Island and Cook Island	Vaughan and Lagus—to Thule Island (Hewison Point and then to Beach Point)	Wynne-Edwards and Fulton—to Thule Island (Beach Point and Hewison Point) and subsequently Cook Island (Reef Point), obtaining angles and distance measurements. Return to ship at midday
				Baker—to Thule Island (Beach Point then to Hewison Point). Later to Cook Island (Reef Point). All return to ship at midday	
p.m.	Fresh and increasing south-westerly winds	Sounding between Southern Thule and Bristol Island	Supporting survey parties. Complete vertical air photographs of Bellingshausen Island obtained	In *Protector* evaluating results obtained in Southern Thule group	Fulton—to Cook Island (Resolution Point) erecting mark. To Bellingshausen Island peak, with remote hydrodist
					Wynne-Edwards and Morrow—to Freezland Rock. Distance to Bellinghausen Island measured
12 Thurs. a.m.	Strong southerly winds; snow	Sounding between Bristol Island and Thule Island	Supporting shore parties	Holdgate and Baker—to Thule Island (Hewison Point). Plant collections and orientated rock samples for palaeomagnetic determinations obtained. Return to ship at midday	Wynne-Edwards—to Bellingshausen Island. Angles to points on Cook Island measured. Return to ship at midday
p.m.	Strong southerly winds; snow; deteriorating	Sounding north to Montagu Island	No activity	In *Protector*	In *Protector*
13 Fri. a.m.	Fresh southerly winds	Sounding between Montagu, Saunders and Candlemas Islands	Inspection and landing of party on Saunders Island	Holdgate, Baker, Vaughan and Lagus—to Saunders Island (northern plain) to camp and undertake geological and biological survey	Wynne-Edwards—to Saunders Island (northern plain) camp to attempt astronomical observations
p.m.	Fresh southerly winds	Sounding towards Candlemas Island	Lifting off generator from Candlemas Island camp for repair		
14 Sat. a.m.	Fresh to strong southerly winds with snow	Sounding between Candlemas and Saunders Islands. Radar photographs obtained	Returning generator to Candlemas Island. Support shore party on Saunders Island	Holdgate, Baker, Vaughan and Lagus—at Saunders Island (northern plain) camp undertaking geological and biological survey	Wynne-Edwards—at Saunders Island (northern plain) camp attempting astronomical observations
				Holdgate—to Saunders Island (Nattriss Point). Baker, Vaughan and Lagus—to ship	Wynne-Edwards—to Saunders Island (Nattriss Point)
p.m.	Fresh to strong southerly winds with snow	Sounding between Saunders and Montagu Islands	Supporting shore parties	Holdgate—returned to ship in evening	Fulton—to Montagu Island; landing impossible
					Wynne-Edwards—returned to ship in evening

Continued overleaf

TABLE I—Continued

March 1964 Date Day Time	Weather	Ship	Helicopters	Scientific parties	Survey parties
15 Sun. a.m.	Strong south-westerly winds	Sounding east of Montagu Island	No activity	Evaluating results	No activity
p.m.	Wind moderating. Moderate south-westerly wind; good visibility	Sounding east of Montagu Island and south to Bristol Island	Supporting survey and scientific operations. Vertical air photographs of Freezland Rock obtained	Baker—to south coast of Bristol Island; rocks collected	Fulton—to Montagu Island (Allen Point) remaining overnight Wynne-Edwards—over Freezland Rock; aerial hydrodist measurement
16 Mon. a.m.	Light southerly winds; good visibility	Sounding northward between islands	Supporting shore parties, especially survey	Baker—Montagu Island Vaughan—Montagu Island; aerial inspection of east coast	Wynne-Edwards—working on board attempting radar verification of range between Bristol and Montagu Islands. Then to Montagu Island (Allen Point and point on north-east ice cap) Fulton—Montagu Island (Allen Point). Distances along east coast of Montagu Island measured
p.m.	Light southerly winds; good visibility	Sounding northward between islands	Supporting shore parties, especially survey	Baker and Vaughan—to Saunders Island (Nattriss Point). Geological and biological survey. Return on board in evening	Wynne-Edwards—to Montagu Island (point on north-east ice cap) Fulton—to Saunders Island (Nattriss Point); distance from Montagu Island measured. Returned on board in evening Wynne-Edwards—to Saunders Island; northern plain for night. Angle and range to Nattriss Point measured
17 Tues. a.m.	Light winds; excellent visibility; some sunshine	Sounding between Candlemas and Saunders Islands. Radar photographs obtained	Transported shore parties. Obtained nearly complete vertical and some oblique air photographs of Vindication Island and some vertical and oblique air photographs of Candlemas Island. Oblique air photographs at Saunders Island	Holdgate and Baker—to Vindication Island Tomblin and Longton—to Vindication Island from Candlemas Island. One-day intensive study of Vindication Island Vaughan and Lagus—to Candlemas Island. Fur-seal survey and photography	Fulton—to Vindication Island. Range from Saunders Island measured Wynne-Edwards—to ship, thence to Candlemas Island. Distance and angles between Candlemas and Vindication Islands measured
p.m.	Light winds; excellent visibility; some sunshine	Sounding around Candlemas Island	Supporting shore parties	As above Holdgate, Baker, Tomblin and Longton—returned to ship in evening	Wynne-Edwards—on Candlemas Island carrying out local triangulation, then to Visokoi Island. Distance and angles to Vindication Island measured Wynne-Edwards—to Candlemas Island camp for night, for astronomical observations Fulton—returned to ship in evening
18 Wed. a.m.	Fresh westerly winds; snow showers	Sounding between Candlemas and Visokoi Islands	Supporting shore parties	Baker, Tomblin, Vaughan and Longton—to Visokoi Island (Finger Point, Irving Point and Sulphur Point). Geological and biological survey	Fulton—to Candlemas Island. Local triangulation on island
p.m.	Fresh westerly winds; snow showers	Sounding between Candlemas and Visokoi Islands	Supporting shore parties	Returned to ship in evening	Wynne-Edwards and Fulton—returned to ship in evening
19 Thurs. a.m.	Fog; light north-westerly winds	Off Candlemas Island	Awaiting chance to lift off surplus stores and personnel from Candlemas Island	Aboard *Protector*	Evaluation of results
p.m.	Temporary clearance of fog	Off Candlemas Island	Lifted off personnel and stores	Lagus returned to ship	Evaluation of results
20 Fri. a.m. p.m.	Fog; light north-westerly winds	Sounding about Zavodovski Island and out to shoal to north-west	Unable to operate	Dredging for rock samples over shoal	Evaluation of results
21 Sat. a.m.	Fog clearing to south-westerly gales; later veering north-west; light snow	Replenished at sea from R.F.A. *Wave Knight*	Established shore party	Holdgate, Baker, Vaughan, Tomblin, Longton and Lagus—to Candlemas Island, consolidating work there and camping overnight	Evaluation of results
p.m.	Fog clearing to south-westerly gales; later veering north-west; light snow	Replenishment in progress	No activity		Evaluation of results
22 Sun. a.m.	Fog with moderate north-westerly winds and snow	Off Candlemas Island	Unable to operate	Party remained in camp awaiting return to ship	Evaluation of results
p.m.	As above, but some clearance just before dusk	Off Candlemas Island	Lifted off shore party	Entire party with Tilbrook and support personnel returned on board	Evaluation of results
23 Mon. a.m. p.m.	Fog; strong westerly winds	On passage to South Georgia	No operations	No field operations	Evaluation of results
24 Tues. a.m.	Fog; moderate westerly winds	On passage	No operations	No field operations	No field operations
p.m.	As above, clearing near the land	At South Georgia (King Edward Point). Sailing again in evening	Landed some stores	Tilbrook and Longton landed at South Georgia for passage to South Orkney Islands	No field operations
25 Wed. a.m. p.m.	Fog patches; light north-westerly winds	On passage	No operations	No field operations	No field operations
26 Thurs. a.m. p.m.	Fog	Off Zavodovski Island sounding and obtaining coastal outline by radar. Sailed at dusk for Bouvetøya	Unable to operate	Unable to operate	Wynne-Edwards undertook radar survey of coast of Zavodovski Island

longitude and for confirmation of latitude, in conjunction with subsequent sun altitudes. During these observations, the observer was linked to a chronograph, which in turn was wired to a portable receiver monitoring time signals from the U.S. Bureau of Standards station WWVH in Hawaii.

Whilst surveying operations were proceeding on Candlemas and Vindication Islands, helicopters from *Protector* obtained vertical and oblique air photographs. As in the case of Bellingshausen Island, these showed the ground control marks and were subsequently used in the production of the large-scale maps. Fortunately, during this period, the distance from Shamrock Hill (Visokoi Island) to Candlemas Island was measured; the weather deteriorated on 18 March and no further observations were possible.

As indicated in the narrative diary, bad weather curtailed operations for the remainder of the period in the South Sandwich Islands group. Although *Protector* waited off Zavodovski Island for several days, thick fog prevented any further flights. An attempt was made to improve the existing map of Zavodovski Island by circumnavigating the island and sketching from the 974 radar picture of the shoreline; no great reliance can be placed on this sketch map but it does suggest errors in the *Discovery II* map of 1930.

With fog persisting on 20 March, *Protector* steamed north-westward to re-examine the shoal discovered in 1962 (Gass and others, 1963). The shoal soundings were generally confirmed and a dredge sample was taken in 22 fathoms [40 m.].

It was unfortunate that weather conditions prevented completion of the traverse to Zavodovski and Leskov Islands. The latter island had been visited at the start of the project but it had not been possible to establish its position relative to the other members of the group. Whilst steaming southward past Zavodovski, Visokoi and Candlemas Islands during changing fixes, an obvious discrepancy revealed itself; with the ship midway between Zavodovski and Visokoi Islands, the radar range broadly confirmed the existing charted distance between the two islands (46 km.). However, the tellurometer distance obtained from Visokoi Island to Candlemas Island (50·6 km.) is at variance with the charted distance (45·8 km.) which would account for the navigational difficulties encountered earlier.

The results of the traverse were compiled with reference to the spot geographical position on Candlemas Island and azimuths, where available, were used for orientation.

Summary of results

1. The positions of the islands, both geodetically and relatively, were established with greater accuracy than on existing charts. There is, however, considerable room for improvement, particularly in view of the weak link between Freezland Rock and Montagu Island, and the fact that the northern end of the traverse was not completed.
2. Some moderately detailed topographic surveying was carried out on Bellingshausen, Candlemas and Vindication Islands. Radar photographs obtained from *Protector*, sketches by shore parties and air photographs were used in revising existing maps of the remaining island.
3. The revised coastlines and positions of the islands, and the bathymetric information derived from soundings obtained by *Protector* during the project, have been incorporated in Admiralty Chart No. 3593 (1968).

D. Climatic Observations

Very few meteorological observations have been made in the South Sandwich Islands. Those carried out over the 20 days of the 1964 survey by Instructor Lt M. J. Cuming with earlier data given by Kemp and Nelson (1931) support deductions about the climate of the island arc from more general publications. The full records have been deposited in the archives of the Meteorological Office, London Road, Bracknell, Berkshire.

The islands are well south of the Antarctic Convergence. In March 1964, the mean sea-surface temperature recorded was 0·6° C and the annual range is likely to lie between +1·5° (as a summer monthly maximum at the northern end of the arc) and −1·5° C. Pack ice probably generally surrounds the whole group from June to November, clearing from the northern islands in December and the southern ones a few weeks later; sometimes, however, the latter remain surrounded by pack ice throughout the year. Air temperatures are likewise low for the latitude, the mean recorded in March 1964 being −0·3° C and the annual range of monthly means probably lying between +3° and −6° C in the northern and −1° and

−11° C in the southern islands; when the group are well within the pack-ice zone, lower temperatures may occur.

The South Sandwich Islands group lies in the zone of the Southern Ocean with a very high frequency of depressions, separated by mobile and short-lived ridges and anticyclones. Prevailing winds are between south and north-west; in March 1964, 26 per cent of winds were south-westerlies, 16 per cent westerlies and 17 per cent north-westerlies. Velocities are normally high and 25 per cent of winds recorded were Force 6, 24 per cent Force 5 and 31 per cent Force 4. Turbulence was a recurrent hazard in helicopter operations when the wind speed exceeded 10 kt [5 m./sec.]. These observations are likely to be typical of summer conditions. Despite the windiness of the climate, visibilities are generally poor with much fog; in March 1964, visibility was below 8 km. for 29 per cent of the observations and fog was usual when the wind had a northerly component. The area is very cloudy; in only 13 per cent of the observations was the cover less than seven-eights. Orographic effects certainly add to cloud cover over the islands. Precipitation is likely to be fairly high by Antarctic standards; during the survey it was recorded in 30 per cent of the observations. Rain and drizzle occurred with north-westerly and northerly winds; snow at other times. Most of the precipitation is certainly as snow.

The climate of the South Sandwich Islands is thus typical of the maritime Antarctic, in its cool, windy, cloudy conditions with some rainfall in summer and appreciable snowfall at all seasons. The southern section of the island group appears to be colder than the South Orkney Islands.

IV. SOUTH SANDWICH ISLANDS

A. Zavodovski Island

1. *Topography*

Zavodovski Island (Fig. 2), the northernmost of the South Sandwich Islands group, is roughly square in outline with the angles forming the northernmost, southern, eastern and western points. The island measures about 5·5 km. from north to south and 4·9 km. from west to east, and consists of a single volcanic cone, Mount Curry, the summit of which lies somewhat to the west of the centre of the island and reaches about 551 m.

The northern, eastern and southern coasts of the island, from Pacific Point eastabout to Fume Point, are low-lying and consist of rock shelves and platforms backed in places by narrow boulder beaches, and surmounted by steep rock cliffs. In places these cliffs rise sheer from the sea. The cliffs are for the most part of uniform height, their crests standing from 15 to 30 m. above sea-level; it is this uniformity in height and monotony in appearance when seen from the sea that makes the coast appear free from indentation and led to its charting by Nelson (Kemp and Nelson, 1931) as nearly circular in outline. The low eastern coastline contrasts sharply with that on the west. Passing from Fume Point westward the land rises suddenly and is bounded by a rather uniform sheer cliff 75 m. high running out to Noxious Bluff. Beyond this headland, the shore swings to the north, curving in a broad bay to the prominent upstanding nose of Stench Point. Along this bay the cliffs and the steep talus slopes above them increase steadily in height and in its centre become virtually continuous with the flanks of the main volcanic cone of the island; this juxtaposition is marked by the presence of a prominent fumarolic area extending virtually to the shore in the centre of the bay. Stench Point itself is the most prominent coastal feature on the island, terminating in a rock platform and shelves backed by a cliff of banded lava and pyroclastic materials which rises sharply for about 90 m. North of Stench Point there is a small rather regularly curved bay backed by further high cliffs cut into the lower slopes of Mount Curry, and north again the shores swing out to a low-lying headland formed by a lava platform and resembling the similarly low-lying eastern and southern coasts. This headland is probably that named "Low Point" in the *Discovery II* survey but the latter feature cannot be positively identified and consequently the headland has been re-named Acrid Point. North of it, the shore turns sharply to the east, the lava platform narrowing below the gullied flanks of the main cone, and then runs north to Pacific Point and Reek Point, where the lava platform attains a considerable width and where the cliffs are low and rise beyond rock shelves.

The coastal features of Zavodovski Island are themselves the result of a rather simple inland topography.

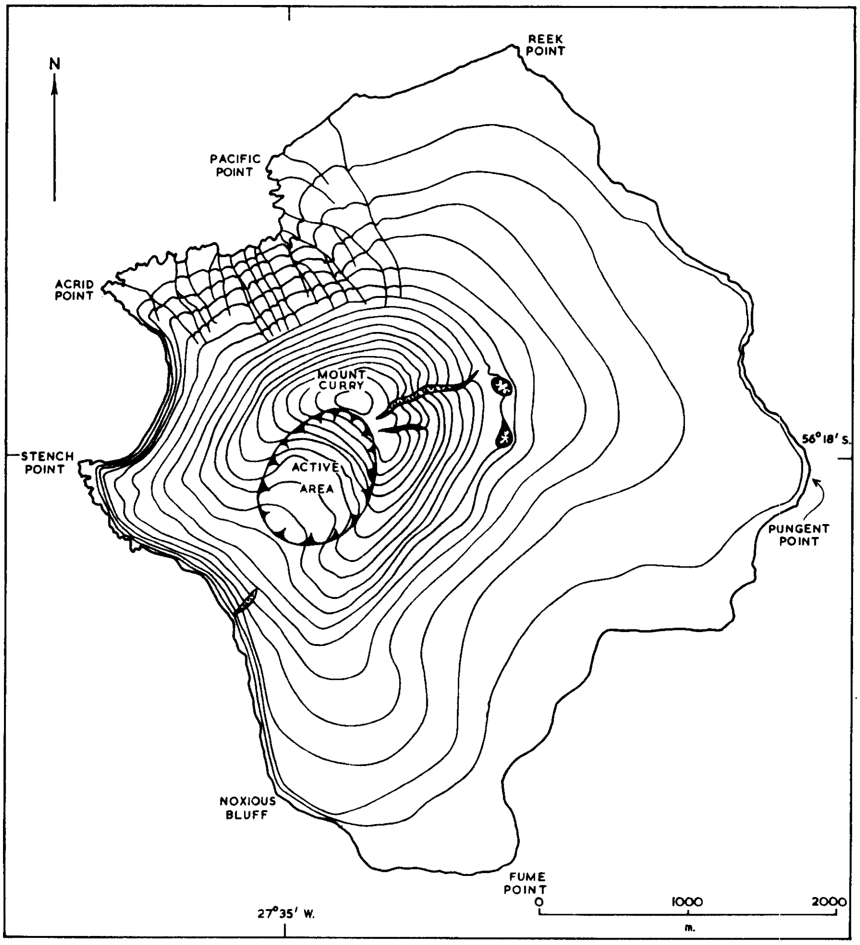


FIGURE 2
Sketch map of Zavodovski Island.

The low northern, eastern and southern cliffs terminate a smooth and uniform plain only partly demarcated into northern and southern halves by a low undulating ridge running towards Pungent Point. The surface of this plain with its low undulations appears from photographs to be composed of dark scoria, and it is traversed by shallow drainage gullies radiating from the main cone. This plain is readily traversed on foot and parties from *Shackleton* penetrated over 1·6 km. inland on 12 January 1961. Similar free movement over this area was achieved by a party landed from the whaling vessel *Slava 15* in 1957 (Ivanov, 1959*a*, *b*).

About 2 km. westward and inland from Pungent Point the ground rises gradually and then more steeply in the flanks of Mount Curry. In this area near its base, the slopes of the peak are broken by two parasitic craters apparently of the explosion type, about 150 m. above the sea and conspicuous in photographs. These are the only parasitic cones to be seen on the island. Above the northern of the pair, the upper slopes of the main cone are further broken by a conspicuous fissure, which, according to Kemp and Nelson (1931), descends from the lip of the main crater at the summit. A second shorter fissure lies somewhat to the south. These two fissures are evidently sites of fumarolic activity since they are snow-free at times when the adjacent slopes are thickly covered.

Elsewhere, the flanks of Mount Curry between north and south fall in rather uniform slopes channelled by drainage gullies, the gradients slackening as they merge in the lowland plain. On the south, a spur of the main peak juts towards Fume Point, but there is insufficient evidence to assess whether it is or was a separate vent. In contrast, on the south-west, west and north-west, the slopes of the cone fall steeply to the edge of the sea cliffs. The fumarolic activity in these cliffs, in the bay south of Acrid Point, has already been noted. Higher up the cone above this bay and above Stench Point there is a much larger area of vapour emission which appears to be a single, rather irregular crater. Lack of observations prevents this being precisely delimited, and its representation on the map is grossly oversimplified.

There is no great thickness of glacier on Zavodovski Island. Snow fields are conspicuous in photographs of the eastern and south-eastern slopes of Mount Curry taken in late February 1930 (Kemp and Nelson, 1931), and it seems likely that these are permanent and that a thin layer of ice may underlie some parts of them. The lack of ice and snow on the eastern plain was attributed by Kemp and Nelson (1931) to volcanic heat but, while this may be a contributory factor (and undoubtedly keeps the western face of the peak clear of snow), the small area of the island may be largely responsible. Vindication Island, which is of comparable height and retains no sign of volcanic activity, is similarly snow-free despite its more southerly position, and on the ice-capped southern part of Candlemas Island the main ice cap terminates at about 120 m. above the western coastal platform. Probably the absence of an ice cap on Zavodovski Island reflects the lack of a large area of highland to act as a centre of accumulation and possibly also the youth of the island, much of which may have been built up since the maximum of the last southern cold period.

Zavodovski Island was surveyed from the sea by Worsley in 1921 (Wild, 1922) and by Nelson in 1931 (Kemp and Nelson, 1931). The former provided a fairly accurate representation of the south-east, south-west and north-east coasts, and his chart is definitely superior to that by Nelson who was probably misled by the uniform aspect of the coast to chart it as nearly circular in outline. This error was noted by radar observation during visits by *Shackleton* in 1961 and *Protector* in March 1962, and on the latter occasion a sketch chart was made correcting the most patent inconsistencies. The height of the island had also been recorded differently by different visitors. Bellingshausen, who discovered the island in 1819, estimated it as 365 m. high; Brown, who visited it in 1830, as 240 m.; Filchner in 1911 as 350 m.; and Kemp and Nelson as 488 m. in 1930. In 1961, five sextant angles obtained from different positions by a party from *Shackleton* gave a figure of 551 m. This last has been taken as correct in preparing the new map, but it does not follow that all preceding figures were in error since the island has shown persistent volcanic activity.

Zavodovski Island has probably been landed on more often than any other in the group. Bellingshausen landed a party in 1819, Brown in 1830, and Larsen in 1908; a party from *Slava 15* went ashore in 1957, and a party from *Shackleton* in 1961. On the last occasion, when the weather was exceptionally calm, a boat was brought in on both the north-east and south sides of the island. It is noteworthy that the landing on the north-east was made at a time when the ship was anchored close inshore, sheltering from a gale. There are probably very many places about the coast where a boat can be brought in provided the swell is not heavy; it is the latter, following round the coast where there are no deep bays and no good lee, that makes landing hazardous since the surge against the rocks is often very great.

A party from *General San Martín* which landed in 1957–58 may have used a helicopter. An inspection from *Protector*'s helicopter in 1962 indicated that these aircraft could be landed almost anywhere on the northern, eastern and southern lowland, provided that the airflow was not too turbulent at the time.

2. *Geology*

The following account is based entirely on the interpretation of oblique air photographs in conjunction with the new map of the island.

Structurally, Zavodovski Island consists of a single volcanic cone flanked to the north, south and east by low-lying lava flows. There is no lowland on the western side of the island, where erosion has cut deeply into the cone, to affect even the summit crater. A shallow submarine shelf extends for some way to the east of Zavodovski Island and is evidently part of the same volcanic edifice. Basaltic cinders dredged from this shelf, about 3 km. from the east coast of the island, are probably some recent products of Mount Curry.

Most of the material forming the cone of Mount Curry has undoubtedly been derived from vents within the area of the summit crater. Some of these deposits can be seen in the steep cliffs along the west coast, although they are often obscured by long scree slopes and by the recent ash cover. A section of Stench Point where the cliffs are about 30·5 m. high shows a basal lava overlain by other lavas which are interbedded with irregularly stratified pyroclastics, many of which are probably re-distributed. The uppermost 5 m. of the section is composed of well-stratified ashes forming a blanket over the former terrain; these are almost certainly undisturbed ash falls of relatively recent origin.

The low-lying lava platform to the north of the cone, and probably elsewhere as well, is apparently mantled by a relatively thin ash cover which may be equivalent to that seen on the cliff top at Stench Point.

The intensive gullying of the low ground to the north of the cone is probably an expression of the susceptibility to erosion of the thin ash cover.

Although most of the cone has been built around the now ill-defined and partially destroyed summit crater, there are evidently secondary centres in the form of explosion craters and fissures on the eastern slopes of the cone. The fissures or bocas within their vicinity may well have been the source of the lava flows which form the low ground. With the present configuration of the summit area, any lava flows emitted from the summit crater would tend to flow down the western side of the cone. The influence of prevailing winds and currents on erosion and on the distribution of pyroclastic falls has probably been sufficient to ensure that throughout most of its history, at least, the lowest part of the crater rim has been on the western side. The actual absence of flows from the western side of the cone in contrast to the extensive lava plains to the east may be explained in various ways. First, it is possible that lava flows were emitted from the summit crater out to the west of the cone but that erosion has proceeded at such a rate that no trace now remains. Some of the earlier flows certainly descended to the west of the cone as indicated by the exposures at Stench Point. It is more likely, however, that the eastern flows have no counterpart in the west and that they were discharged from fissures or bocas low on the eastern slopes of the cone. This suggestion is supported by the fact that fissures can still be observed on this side of the cone and also by the presence of a gentle but distinct ridge which originates in the vicinity of the fissures and extends eastward towards Pungent Point. This ridge probably marks the course of a lava flow.

The general succession on Zavodovski Island would appear to be:

3. Series of pyroclastic falls (basaltic cinders).
2. Emission of basaltic lava flows from the eastern flank of the cone.
1. Construction of the cone—lava flows, agglomerates and pyroclastics.

Zavodovski Island was emitting copious fumes from a crater near its summit at the time of its discovery by Bellingshausen in 1819, and a party from his ship *Vostok*, who landed and climbed half-way up the mountain, found the ground warm and the smell unpleasant. In 1830, Brown, who also landed, reported similar intense emission of vapour and noted in addition that a level field of apparently fresh pumiceous lava lay on the east side and was breaking away and floating in large masses on the sea nearby. This appears to be the only record of lava emission since the discovery of the island. Records in 1911 (Filchner), 1922 (Wild), 1927 and 1930 (Kemp and Nelson), and frequently since 1950 all agree in their description of vapour emitted as a plume from the main crater somewhat west of the summit. Fumarolic activity in the western cliffs south of Stench Point was recorded by Kemp and Nelson (1931) and a photograph they included is almost identical with one of the same area taken from *Protector* in 1962. Fumaroles, apparently on the east side, not far from Pungent Point were suggested by Larsen (1908) in the account of his celebrated landing there, when he suffered severely from inhaling the poisonous vapours. Other fumaroles emitting sulphurous fumes were noted on the south coast by Wild (1922). However, the party from *Shackleton* which traversed the eastern plain in January 1961 was not troubled by fumes and recorded only the continuous activity of the main peak. In 1962 and 1964, during visits by *Protector*, the pall of vapour had a noticeably sulphurous smell even some miles from land, but this was not intense enough to be troublesome.

3. *Vegetation and fauna*

No biologist has landed on Zavodovski Island so that it remains the least known of the archipelago from this point of view. Kemp and Nelson (1931) recorded "green staining" at one point, looking from the sea, and on the northern slopes near a penguin colony described "the most extensive patches of green vegetation seen in the islands". These they considered most likely to be growths of the green alga *Prasiola crispa* which is characteristic of such situations. On 15 March 1962, during a helicopter flight over the northern coasts of the island, Holdgate noted "green slopes of *Prasiola* and perhaps a little moss, but not good vegetation", but he was unable to land and confirm the identifications. In a subsequent note he recorded the moss as forming "orange patches" and suggested it might be *Polytrichum alpinum*. Mosses, lichens and *Prasiola* were collected on the island by the party landed from *Shackleton* in 1961 and it is likely that areas of the eastern plain support a vegetation not unlike that on the topographically and edaphically similar gullied platform on the west coast of Candlemas Island (Longton and Holdgate, 1979). The fumaroles known to exist on Zavodovski Island must be expected, however, to support a richer bryophyte vegetation in certain areas, and it is possible that the eventual floral list will be considerable.

All visitors to the island have commented upon its very large penguin colonies. These are conspicuous on the northern slopes and also near the southern platform and on the flanks of the cone above Noxious Bluff. In March 1962, penguins were so abundant as to form prominent white patches on north and south slopes of the cone to quite high levels, and a large group also occupied the smooth slopes above Stench Point to which they gained access up a steep slope just north of the headland. At this season it may be confidently asserted that the bulk of the penguins would be moulting chinstraps (*Pygoscelis antarctica*), the dominant species in the South Sandwich Islands group. Larsen (1908) recorded macaroni penguins (*Eudyptes chrysolophus*) ashore, while Kemp and Nelson (1931) claimed to have recognized from the sea both gentoo (*Pygoscelis papua*) and king penguins (*Aptenodytes patagonicus*). Brown, who landed in 1830, claimed the existence of five kinds of penguin, and Kemp and Nelson commented that the Adélie (*Pygoscelis adeliae*) probably occurs; this would permit Brown's statement to be correct. Ivanov (1959*b*) recorded *Pygoscelis antarctica* as most abundant in December 1957, with *Eudyptes chrysolophus* less numerous and *Pygoscelis adeliae* rare. He also noted giant petrels "in separate groups" (possibly breeding) and skuas. It is particularly unfortunate that these records could not be confirmed by landings in 1962 or 1964. There is only one other report of king penguins in the South Sandwich Islands group, and none was seen there at any time in 1964; enquiry among members of the scientific staff of *Discovery II* who were aboard during her survey of the islands in 1930 suggests, moreover, that the record on that occasion was less certain than Kemp and Nelson implied. This is a matter requiring further investigation. Another anomalous bird record for Zavodovski Island is the light-mantled sooty albatross (*Phoebetria palpebrata*) (Murphy, 1936). In March 1964, when *Protector* lay at anchor off Pungent Point, five of these birds were seen flying in the fog near to the ship, and this was a larger total than at any time in the 3 weeks spent in the islands. However, the observations were made after several days of north-westerly winds which could bring the birds southward, and Zavodovski Island, being the island nearest to their normal feeding zone, is the most likely place for such records to be made. Breeding on the island seems most unlikely in view of the severity of its climate at the season when these birds commence to lay.

In December 1957, Ivanov (1959*b*) encountered a "female fur seal which became agitated when approached and protected her young by attacking the visitors". The party from *Slava 15* also noted elephant seal hauled out on the rocks of the south coast. Several fur seal were seen ashore on the island by the party from *Shackleton* in 1961, and the coasts in several places appear suitable for a breeding colony of this species. Mention has already been made of the probable taking of seal at this island during the nineteenth century.

B. Leskov Island

1. *Topography*

Leskov Island (Fig. 3), the smallest and westernmost of the South Sandwich Islands, lies near the northern end of the group in a somewhat anomalous position about 56 km. west of the arcuate axis on which the remaining islands lie, and about 60 km. south-west of Zavodovski Island. Seen from the west, the island has the two-tier form of a cottage loaf, with a curved centre section of rather uniform breadth, prolonged by two narrower extremities following the same line of curvature, in the north-east and south-east. The overall length, from north-west to south-east, is 900 m., while the maximum breadth in the centre of the island is 460 m.

The south-eastern point of the island, Rudder Point, is formed of a prominent conical tower of rock almost circular in plan and rising on all sides in steep and rugged cliffs from the sea. Its summit reaches 115 m. and is a jagged pinnacle; to the north-east the ridge descending from the summit towards the neck linking the point to the main mass of the island is surmounted by further pinnacles, which from some angles appear as regularly spaced as the teeth of a saw's blade. The neck connecting Rudder Point to the main island is only 75 m. across and about 23 m. above the sea.

The east coast of Leskov Island, north-west from Rudder Point consists of a single embayment, Crater Bay. This is bordered by very steep cliffs of lava and tuff rising for about 120 m. Only a few small areas of coarse boulders, most of them awash, lie at the foot of these cliffs; there are no beaches. Crater Bay ends at the northernmost point of the island, Bowsprit Point, which is a narrow spit of rock rising sheer from the sea, and with a summit arête rising progressively from the 60 m. cliffs at the end of the headland to its

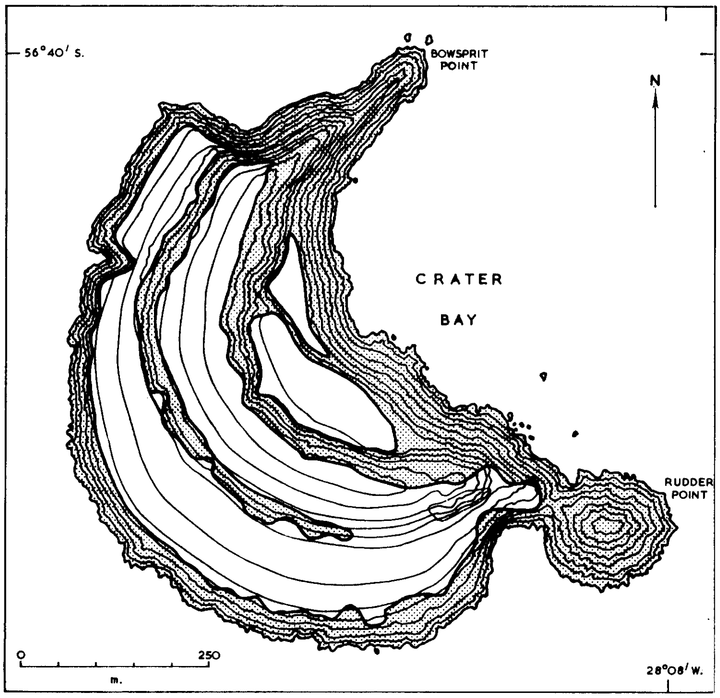


FIGURE 3
Sketch map of Leskov Island.

junction with the main mass of the island. In its upper parts, near this junction, the ridge of Bowsprit Point is surmounted by several prominent pinnacles of rock similar to those capping Rudder Point.

Westward from Bowsprit Point there is a shallow embayment flanked by very steep cliffs which rise almost unbroken to the summit ridge of the island, about 185 m. above the sea. These cliffs are recessed in several places by tall caverns of no great depth. Farther west, beyond this bay, the west and south coasts of the island follow a uniform convex curve and are backed by regular cliffs of lava about 60 m. high. Like the cliffs of Crater Bay, these have no beaches below them and, like those of the northernmost embayment, some are recessed by clefts and shallow caves. In the south-east of the island this regular curve of cliffs runs into and terminates in a small square-cut cove at the neck of the Rudder Point headland.

The internal topography of the island is relatively simple. Above the cliffs of the curving west and south coast rather uniform talus slopes rise at about 15° for almost 60 m., forming an inclined terrace around this side of the island. Above this terrace, at about the 120 m. level, there is a break in slope formed by a discontinuous girdle of lava cliffs and outcrops, varying in height from about 45 m. near the northern end of the island to under 6 m. in the south. In the south there is a broad gap in the cliff line, the talus slopes below and above merging, although still with an evident change of angle. All around the western side of the island small gullies also break the cliff girdle. Higher up, the uppermost slopes of talus, inclined at an angle of about 20°, lead up to the summit ridge of the island, into which they grade with a smooth convexity. The summit ridge itself, which extends from the landward end of the Bowsprit Point promontory to the end of the ridge overlooking the Rudder Point neck, attains a rather uniform height of about 185 m., and a maximum elevation of about 190 m. For the most part, this ridge is mantled by debris but a scoriaceous lava crops out at its lower eastern end.

The regular terraced aspect of the south and west of Leskov Island contrasts with its precipitous topography above Crater Bay. On this side the summit ridge falls steeply in a ring of broken cliffs for about 25 m. to a prominent platform covered by yellowish ash which appears as a broad crescentic shelf cut into the higher part of the island. Below are the steep main cliffs of Crater Bay which to the north and south of the platform are continuous with those of the summit ridge.

There is no ice cap on Leskov Island and in March 1964 there were only a few tiny patches of snow above the southern cliffs. These probably do not persist in all seasons.

Leskov Island was surveyed from the sea by *Discovery II* in 1930 (Kemp and Nelson, 1931). Their map is in broad general agreement with that now produced as a result of vertical air photography. At the time of *Discovery II*'s visit, the crest of the island was in cloud and the height therefore guessed at 185 m., but this figure agrees with 190 m. estimated by *Shackleton* in 1961 and has been accepted by us.

Prior to our own visit there is only one record of a landing on Leskov Island. On 8 January 1961, three men from *Shackleton* were landed from a boat, in exceptionally calm weather, on a small rock ledge on the south-west side of Rudder Point. It was considered that access from this place to the rest of the island was possible but it would be difficult. The sheer girdle of cliffs about the island probably provides no more favourable landing place and, in view of the normal heavy swell and the small size of the island, the use of boats to get ashore must generally be impossible. On 5 March 1964, five men from *Protector* were landed by helicopter on the sloping talus of the lower terrace near the south point of the island. Even in this place, the helicopter could not land fully but had to maintain a hover with the two "up-hill" wheels just touching the ground. Under certain weather conditions helicopters might also land on the summit ridge or even the platform above Crater Bay but local turbulence must often be severe in the latter place.

2. *Geology*

As interpreted by Kemp and Nelson (1931, p. 161), the island is undoubtedly the surviving part of a once much larger volcanic cone. Crater Bay is aptly named as it was almost certainly the site of the principal eruptive centre. The structure of the island appears to be relatively simple; it may be divided into three geological units, which together with their approximate thicknesses are as follows:

		m.
3.	Stratified ashes	9
2.	Upper andesitic lava	18
1.	Lower andesitic lava	152

The lower lava crops out all the way around the base of the island, forming the cliffs on the western side, the conical mass of rock at Rudder Point and almost the entire cliff overlooking Crater Bay. There was nowhere any indication that this great thickness of columnar-jointed lava is built of several separate flows. The red and yellow staining in places on the eastern cliffs is perhaps the result of former fumarolic activity. The lava is a strongly porphyritic pyroxene-andesite and it is for the most part reddish and vesicular; fresh examples are not readily obtainable.

The upper lava is very similar to the lower one and may well belong to the same eruptive episode. This flow, which is about 18 m. thick, crops out around the crater rim along the crest of the island and appears again in the arc of cliffs 122 m. above sea-level on the western slopes.

The well-stratified pyroclastic deposits which crop out on the gently sloping platform about 25 m. below the crater rim on the eastern side of Leskov Island have a total thickness of about 9 m., the upper part of which shows the following units:

	cm.
Pale ash	15
Fine black ash	2
Pale ash and blocks	30
Purplish ash	60+

This small succession of ashes probably belongs to the most recent eruptive episode and may have been emitted from a small vent inside the old crater.

The scree slopes covering much of Leskov Island are composed of ash and lapilli with assorted angular to sub-angular blocks, mostly porphyritic, and apparently largely of an andesitic composition; some of these blocks have bread-crust surfaces. Darker basaltic blocks are less common and coarse-grained gabbroic blocks are present but they are rare.

Assuming that Leskov Island was once a complete volcanic cone, it is perhaps at first sight surprising that the western half of the cone, i.e. the half most exposed to the westerly winds and currents, is the part which has survived. The reason may be that the eastern part of the cone was more susceptible to erosion in spite of its more protected position. This suggests that pyroclastic deposits may have formed the bulk of the missing eastern part of Leskov Island, in contrast to the lavas which constitute the remaining western half. The concentration of lava to the west of the crater may have been determined by the initial configuration of the cone. If the earlier activity was mainly explosive, westerly winds would undoubtedly have carried most of the erupted pyroclastics to the east of the vent, thus constructing an asymmetric cone, high to the east and low to the west. Following the initial pyroclastic activity, when lava flows were emitted, they would naturally have breached the cone on its western side where it was lowest and most vulnerable. On the cessation of activity, erosion would have proceeded to remove the pyroclastics at a greater rate than the lavas, until the present situation was reached when only part of the lava remains. This suggested reconstruction of the major events in the evolution of Leskov Island is illustrated diagrammatically in Fig. 4.

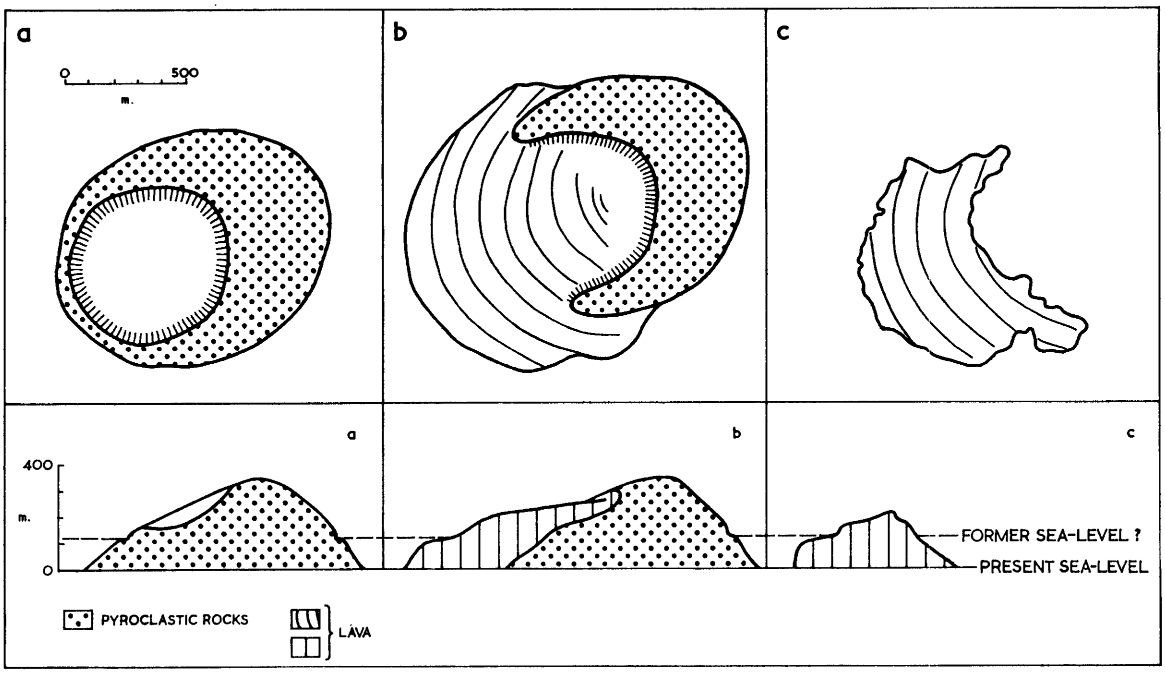


FIGURE 4

Stages in the volcanic evolution of Leskov Island. The three upper diagrams are plans of the island showing its areal extent at different stages, whereas the three lower ones are cross-sections showing the relationship of the island's relief to sea-level.

Prior to the recent survey, the only report of volcanic activity on Leskov Island was by Filchner in 1911 (Filchner, 1923) and this was tentative. Puffs of white vapour, which might equally have been steam or drift snow, were seen rising from the summit ridge. Kemp and Nelson (1931), themselves unable to examine the question because of low cloud, thought the earlier statement by Larsen (1908) that the island was extinct was the more plausible, although they (as at Zavodovski Island) attributed the lack of ice cover to volcanic heat.

In 1964, a series of fumaroles along the eastern margin of the summit ridge, especially in its northern half, were emitting steam. Steam was also emerging from crevices in the upper part of the cliffs overlooking Crater Bay and in one area on the northern slopes of the island. Towards the northern end of the west coast is a narrow inlet which penetrates further inland than most; at the head of this inlet the lava has been appreciably decomposed by fumarolic action and, although there was no sign of vapour in March 1964, there was a distinctly sulphurous odour in the vicinity. The presence of rich mats of bryophytes about these areas renders them conspicuous. It was estimated that at a depth of about 15 cm. in fumarolic areas the temperature of the ground was generally at between 30° and 40° C. The vapour was largely steam but there was some sulphurous smell.

Despite this confirmation of fumarolic activity, it is considered that the lack of ice cover on the island results more from its small extent and low altitude; even a few metres away from the fumaroles, the ground was hard frozen at the time of our visit and snow must lie widely on the surface in winter.

3. *Vegetation and fauna*

Around the fumarolic areas of Leskov Island there were in March 1964 substantial mats of mosses and hepatics, in places 20 m. across and merging with those surrounding nearby vents. Away from these warm areas, the north and west slopes of the island supported localized patches of moss, often partly buried under wind-blown scoria; these occurred in almost all stable places. Lichens, both of the encrusting and foliose types, grew on numerous rocks, while the green alga *Prasiola* occurred in the drainage areas below bird colonies. This vegetation will be described in detail elsewhere (Longton and Holdgate, 1979). Soil and bryophyte mats yielded abundant Collembola and mites, discussed by Tilbrook (1967*a*, *b*).

No penguins have been seen on Leskov Island, probably because the sheer coasts make it unusable as a breeding ground. Cape pigeons (*Daption capensis*) breed on the ledges of the upper cliff line on the northern slopes and on the cliffs above Crater Bay; on 5 March 1964, some nearly fledged chicks remained. Southern fulmars (*Fulmarus glacialoides*) were seen on ledges above Crater Bay and a dead adult was found near the summit. At the south-eastern end of the summit ridge a large patch of moss was tunnelled by burrows almost certainly belonging to dove prions (*Pachyptila desolata*), one adult of which was seen over the slopes. A pair of wings of a snow petrel (*Pagadroma nivea*) conjoined by the pectoral girdle, and indicating skua predation, was seen on the south slope; these birds were recorded by Larsen as breeding on the island in 1908. The breeding avifauna may also include a few brown skuas (*Catharacta skua lonnbergi*), one of which was seen over the land. Wilson's petrels (*Oceanites oceanicus*), which were seen hawking in their characteristic manner above the northern slopes, are almost certainly also among the breeding population.

No seals have been seen around the island and, since suitable hauling out places are lacking, it is unlikely that they occur.

C. Visokoi Island

1. *Topography*

Visokoi Island (Fig. 5) is oval in shape with its broad end towards the west and its long axis aligned almost due east–west. It lies about 45 km. from Zavodovski Island and 58 km. east of Leskov Island. The greatest length, from Sulphur Point to Irving Point, is 8·3 km. and the maximum width, between Finger Point and Mikhaylov Point, is about 6 km. The summit, Mount Hodson, which lies toward the west of the centre, rises to about 1,005 m.

The coastline of Visokoi Island is largely formed of high rock cliffs alternating with precipitous ice falls. For the most part, the coasts are regular, being broken only by occasional projecting headlands all of which are relatively small and low-lying. Irving Point, the easternmost extremity of the island and conspicuous in views from north and south, consists of a partly submerged rock reef backed by a succession of black sand beaches which in turn fringe the base of a cinder cone about 60 m. high. From this headland, passing westward along the south coast, the shore continues to be bordered by off-lying rocks of no great height for about 1 km., but the continuity of the landward slopes is broken by a small glacier ending in an ice cliff immediately west of Irving Point. Beyond this glacier further rock cliffs, a second and much broader glacier and a series of rock cliffs of increasing height succeed one another and lead to a steep ice fall above the narrow projecting spit of Mikhaylov Point. This spit, which may be of morainic material, is the southernmost point of the island, and beyond it the coast trends a little north of west and is largely formed by very high, sheer rock cliffs of about 500 m. overhung by seracs. Some of the gullies in these cliffs are evidently swept by falling ice and snow, and there are two substantial but narrow tongues of ice which descend almost to the sea at the south-west corner of the island, just east of Wordie Point. From the sea, this section of the coast has a gabled aspect, the cliff buttresses rising to triangular crests which are separated by the descending wedges of ice.

There are two small projecting rock headlands in the south-west corner of Visokoi Island. One of these is a nameless jut of cliff about 50 m. high with off-lying reefs. The second and westernmost is Wordie Point, at which the coast turns rather sharply through 90° and runs north. The point itself is a convex bluff falling to the sea in terraced cliffs and surmounted by a substantial area of snow- and ice-free ground,

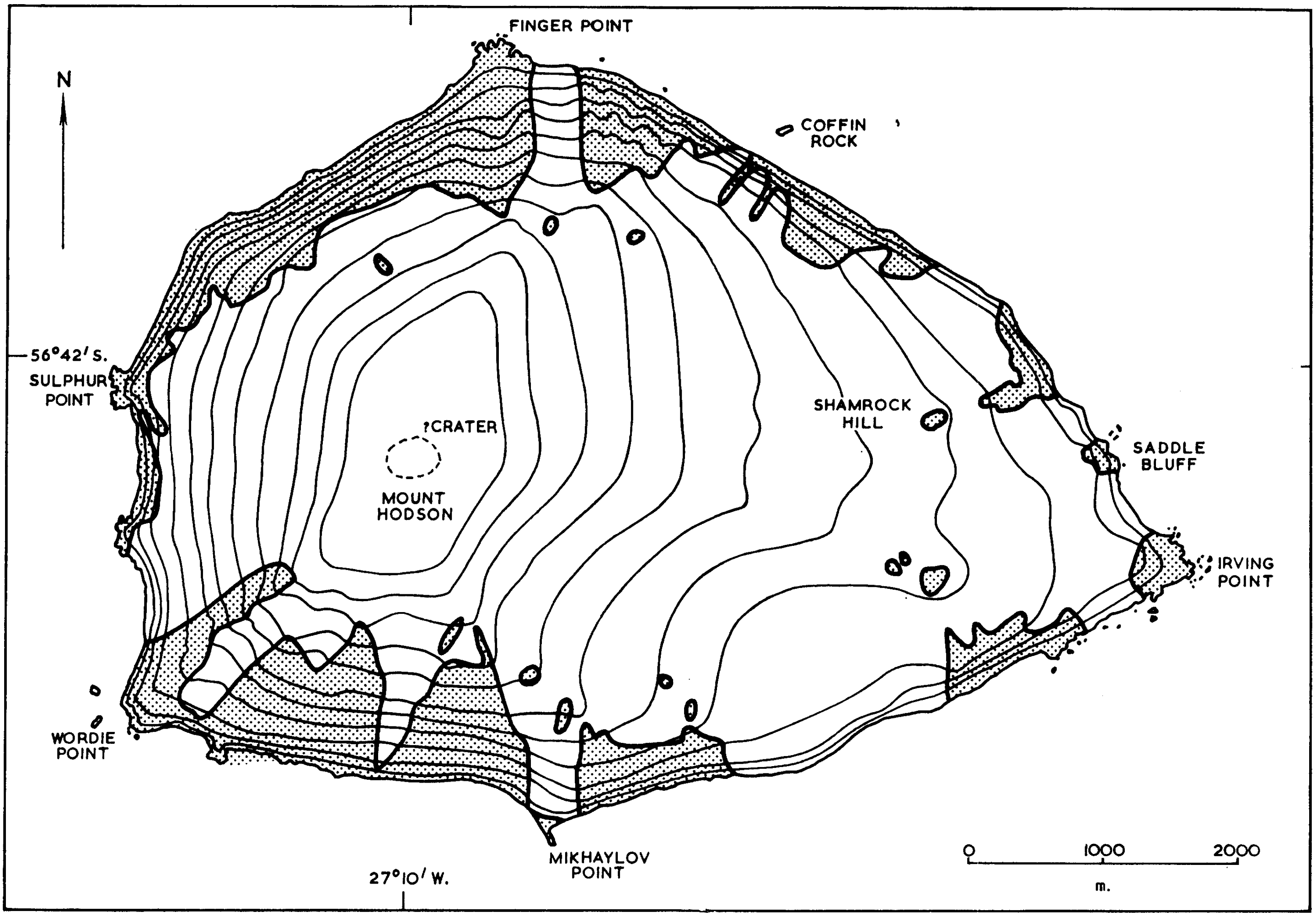


FIGURE 5

Sketch map of Visokoi Island.

which runs up to the foot of a high and rocky buttress on the side of Mount Hodson. This ice-free ground above Wordie Point appears in photographs taken in 1962 to be partly covered in avalanche debris. West and north-west from Wordie Point there are two prominent off-lying rocks.

Passing north from Wordie Point to Sulphur Point, the coast curves into two shallow bays divided by an unnamed low headland of lava. Above both bays the cliffs continue but they are less steep than east of Wordie Point and very largely covered by a tumbled mass of crevassed glacier falling from Mount Hodson. Sulphur Point is formed of a narrow even-topped ridge about 75 m. high which broadens somewhat to seaward and is truncated by a cliff and talus slope. This falls to a lava platform about 10 m. above the sea, divided by a cleft into two lobes.

From Sulphur Point to Finger Point, at the northern extremity of Visokoi Island, the coast trends north-north-east and then north-east, and is rather regular in form. All along this section it is backed by high and steep rock cliffs, surmounted at about the 400 m. level by ice. Debris of fallen ice is conspicuous in the gullies of these cliffs and in spring avalanches must sweep the whole way to the sea. Finger Point, however, provides a contrast in that it consists of a triangular lobe of lowland jutting out into the sea, fringed by a reef. The promontory is at the most about 275 m. wide and extends for about 180 m. from the foot of the cliffs. It consists of a rough platform about 6 m. above sea-level which is fringed by innumerable small headlands and inlets. Although the surface is partly obscured by a thin mantle of debris, it is evident that the feature is part of a single lava flow. The inner part of the lowland is covered in debris from a large talus fan descending from a gully in the cliffs behind, but there are areas of relatively stable ground supporting vegetation, especially in the vicinity of a fumarole which occurs here. Finger Point is probably named not from the form of the lowland but from a conspicuous tower of rock rising at the apex of a buttress immediately above the point.

East of Finger Point the coast trends east-south-east and the cliffs are broken by a glacier descending right to the sea. Further cliffs rise beyond this ice front but they diminish steadily in height to the eastward and are increasingly replaced by ice falls. Off this run of coast, which swings gradually to the south and diminishes steadily in the height of its ice and rock cliffs, there are several conspicuous rocks of which Coffin Rock, 2·2 km. east-south-east from Finger Point, is the largest and most obvious. By the time Saddle Bluff, a small cinder cone with off-lying reefs 500 m. north of Irving Point, is reached, the height of the rock and ice cliffs has diminished from the 400–500 m. of the Finger Point area to only about 30–100 m.

The inland topography of Visokoi Island is remarkably simple. Like the coastal cliffs, the bulk of the island increases steadily in height from east to west, at a mean angle of slope little exceeding 10°. Most of these eastern slopes are made up of an undulating field of crevassed ice, the rock outcrops above the coastal cliffs continuing for no distance inland. However, this eastern slope is broken by two prominent secondary volcanic centres. One of these, about 2 km. west of Irving Point, is well preserved and probably of very recent origin. The second, which lies about 1·2 km. farther north, is a little less regular. The northern of the two cones, Shamrock Hill, was the site of an important survey station in 1964.

To the south-west of the ridge linking the southern cone to the lip of Mount Hodson is a broad shallow hollow which is bounded on the south by the tops of the coastal rock and ice cliffs above Mikhaylov Point. On the south, west and north flanks of Mount Hodson, the smooth upper slopes of the mountain similarly descend into increasingly tumbled ice falls above the high cliffs. In photographs, the actual crest of Mount Hodson appears as a smooth even platform of almost uniform height. Observations by Kemp and Nelson (1931) suggested that its centre is broken by a small crater but no information about this is available.

Visokoi Island is one of the most heavily ice-covered of the South Sandwich Islands group, although perhaps because of their steepness its western, northern and southern sides have less continuous ice cliffs than the larger southern Bristol and Montagu Islands. In much of the lower-lying area, scoria covers parts of the ice, probably owing to minor recent eruptions or to the exposure by ablation of ash bands deposited from earlier activity.

A sketch map of Visokoi Island was made by C. A. Larsen in 1908 and the island was surveyed from the sea from *Discovery II* in 1930; no further survey has been made. The present map is based on the *Discovery II* coastline, supplemented by the sketching of detail (especially of headlands and interior) from oblique air photographs taken from a helicopter in 1962. The height of the island was not determined in 1930, but in 1962, when the top was clearly seen through thin cloud, the helicopter ascended almost to summit level and estimated its height by altimeter as 1,005 m. The secondary cone, Shamrock Hill, 2·2 km. north-west from Irving Point and 1·5 km. west-north-west from Saddle Bluff was the northern terminal point in the tellurometer traverse undertaken in March 1964.

The first recorded landing on Visokoi Island was made by helicopter from *Protector* at Finger Point in 1956. A landing was made by the same means at Irving Point in 1960. In January 1961, a party from *Shackleton* landed by boat near Finger Point. In March 1964, helicopter landings were made at Irving Point, Finger Point and Shamrock Hill; a man was landed by winching at Sulphur Point. As at all the islands, boat landings depend on rare conditions of calm, and helicopter operations are liable to limitation by turbulence.

2. *Geology*

The sea cliffs of Visokoi Island are composed of interbedded lavas and pyroclastics which dip fairly consistently away from the interior at angles varying from 5° to 20°. Thick columnar-jointed lavas form the cliffs at Wordie Point and low-lying lava platforms project from the base of the cliffs at both Finger Point and Mikhaylov Point. The bulk of the material exposed around the coast has almost certainly been emitted from the main volcanic centre on Mount Hodson.

The seaward part of the promontory at Sulphur Point consists of a lava platform about 10 m. above sea-level; immediately behind the platform are irregularly stepped cliffs composed of thin lava flows interbedded with scoriaceous pyroclastics. Above these, the promontory is linked to the main cliffs of the island by a scree-covered ridge. The platform is cut by a series of basaltic dykes all trending at about 190°, i.e. approximately parallel to the trend of the main cliffs, and dipping at about 80° to the east. The preservation of the Sulphur Point promontory is possibly due to the protective effect of these dykes. Immediately to the north of Sulphur Point, the following succession was noted in the main cliffs:

	m.
Glacier	6
Thin lava flows with rubbly horizons	12
Brown ash with blocks (possibly re-distributed)	6
Lava	3
Red scoria and blocks	2·4
Lava	2·4
Red scoria and blocks	1·2

The low area at Finger Point (Figs. 6 and 7) is composed of a lava flow which is probably of relatively recent origin in comparison with the material in the cliffs behind. The surface of the lava is roughly corrugated into broadly concentric ridges and furrows emphasized by patches of snow and pools of water lying in the hollows; these features are probably large-scale flow structures. In the hand specimen the lava is dark grey and fine-grained, although occasional small phenocrysts of feldspar and olivine may be seen. The scree which descends behind Finger Point is composed of fragments of the lavas, pyroclastics and dykes forming the cliff above. At the western side of the Finger Point promontory, a different lava, which

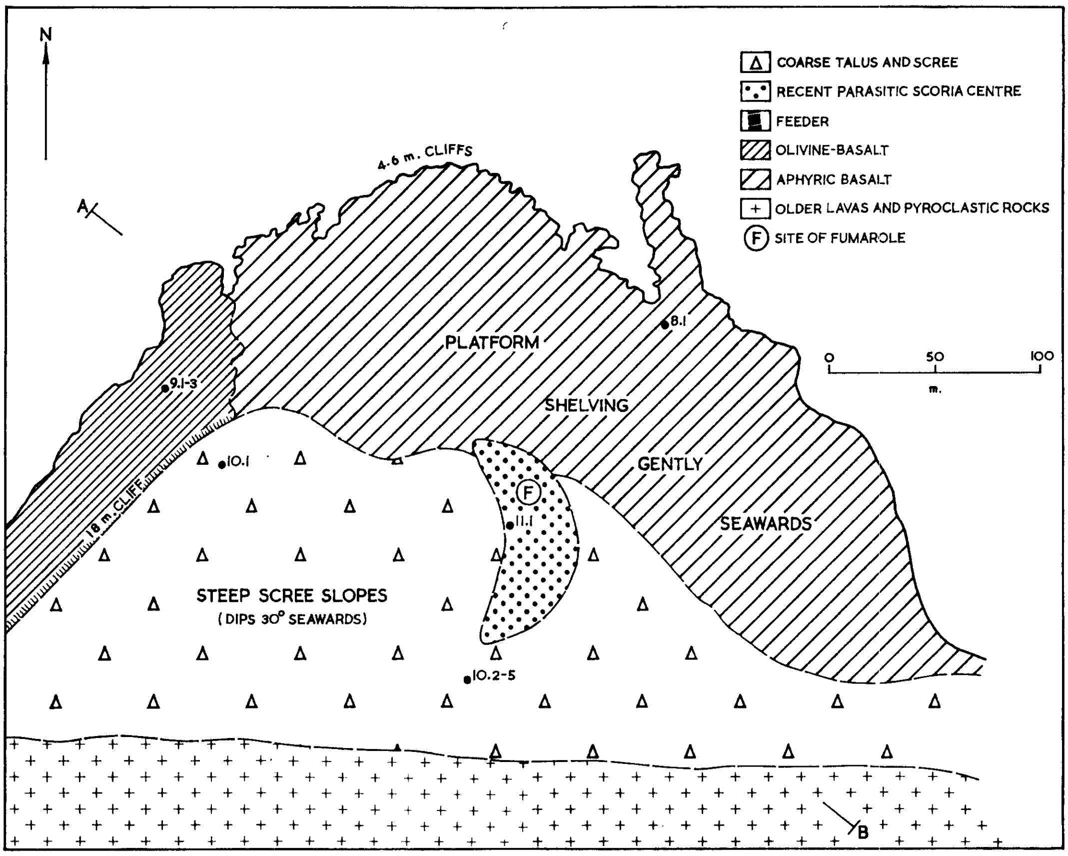


FIGURE 6

Geological sketch map of Finger Point, Visokoi Island. The cross-section A–B is given in Fig. 7.

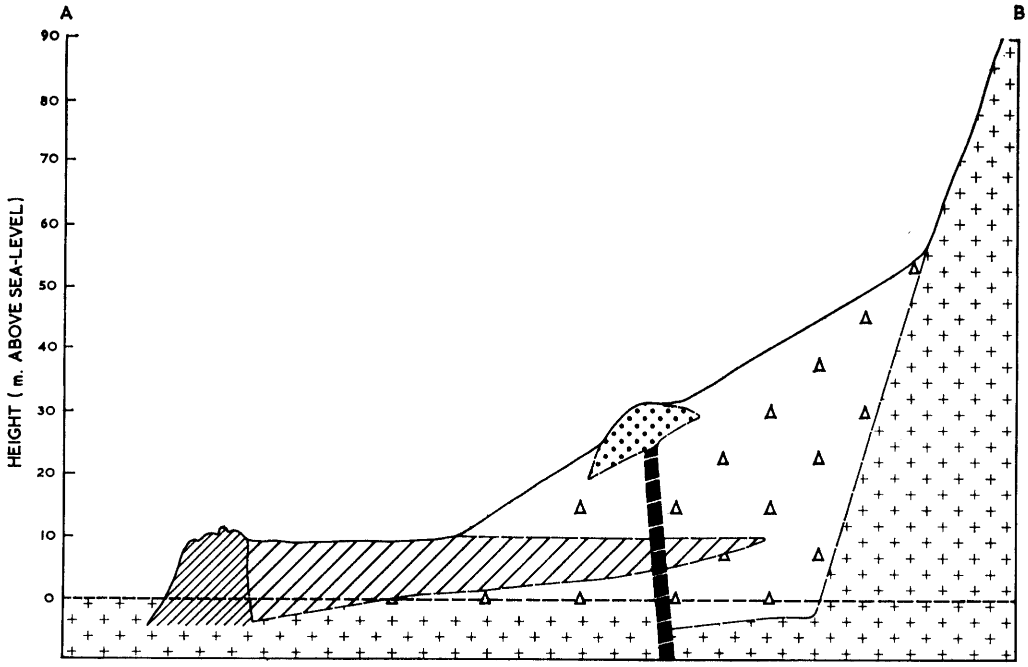


FIGURE 7
Cross-section A–B across Finger Point, Visokoi Island. The legend in Fig. 6 also applies to this diagram.

is probably considerably older, forms cliffs about 18 m. high; here the cliffs are backed by scree but they appear to merge with the main cliffs of the island a little way to the south-west. The lava, a basalt, is paler in colour than that at Finger Point itself and it is distinctly flow banded. It has a closely jointed, almost flaggy structure near the base but this passes upwards into more massive lava. It is a very fine-grained plagioclase-clinopyroxene rock containing a few small olivines.

Several parasitic pyroclastic centres occur on the flanks of Mount Hodson; one of these, a crescentic mound of red and black scoria with no evidence of a crater, projects through the lower part of the long scree slope behind Finger Point. It is clearly a very recent centre which has been partly obscured by avalanches of debris from the main cliffs. In places along the higher part of this mound, the ground was distinctly warm in March 1964, permitting the growth of small patches of moss. There was no visible vapour rising from this area but it is likely that fumarolic activity has only recently reached its present diminutive proportions.

One of the most conspicuous of the secondary centres is Shamrock Hill, located on the eastern slopes of Visokoi Island approximately 0·8 km. inland from Saddle Bluff. It is entirely free from ice and consists of an asymmetric mound of reddish scoria and cinders together with numerous blocks and bombs. The mound is elongated in an east–west direction down the slope of the island with a short, steep western side inclined against the general slope of the terrain and a long tapering eastern slope dipping seawards at about 15–20°. The highest point rises about 18 m. above the general surface level. There is no crater but just to the south of the mound are two parallel ridges, 9 m. and 4·5 m. high, separated by a furrow; both ridges, like the mound, are composed of the same scoriaceous material containing blocks of basaltic andesite. The disposition of the arcuate ridges suggests that they have been constructed by material ejected from a crater which lay to the north. It is possible that this crater was located below, or slightly to the south of, the highest part of the mound and that the final phase of activity involved the dome-like upheaval of a viscous lava which is now largely concealed beneath a mantle of loose scoria. The blocks of lava which occur amongst the scoria may have been derived from an underlying dome.

The southern secondary centre projects through the ice about 1·2 km. west of Irving Point and 0·4 km. inland from the south-east coast. This low symmetrical cone is also built of red and black scoria, and appears to have a small crater, although it was only observed from a distance. A further small parasitic centre, again with no evidence of a crater, lies above the lavas at Irving Point but in this case the dominant material appears to be brown ash with lapilli.

To summarize, it would seem that Visokoi Island is a single stratovolcano constructed mainly of basic lavas and pyroclastics injected by dykes. It has been subjected to intense marine erosion, particularly on its western side, and in very recent times a number of secondary centres, built largely of basaltic scoria and cinders, have been constructed on the lower flanks of the main volcano.

Visokoi Island appears to have been rather active in 1830 when Brown referred to it as "a burning mountain with smoke issuing from it in several places". In 1927, it was seen twice with a white stream of vapour issuing from the summit and in 1930 a similar plume from Mount Hodson was observed from *Discovery II* (Kemp and Nelson, 1931). No activity of the summit crater has been seen since, and none has ever been recorded from the small subsidiary cones on the eastern ice cap and at Irving Point and Saddle Bluff. In 1930, however, fumarolic activity was seen at a point which, from the sketch published by Kemp and Nelson (1931), can only have been about half-way up the scree above Finger Point. This was not evident in 1962 but in 1964 a patch of warm ground was located on the scree in a position comparable to that of the fumarole shown in Kemp and Nelson's sketch.

3. *Vegetation and fauna*

The fumarole above Finger Point was, in March 1964, surrounded by mats of moss and hepatics, while lichens grew on the surrounding area of bare broken scoria and debris. Away from the fumarole, vegetation on the island was largely lacking, consisting of sparse moss and lichen patches on the rocks and areas of *Prasiola* in the vicinity of bird colonies. A detailed account and check lists will be given by Longton and Holdgate (1979). Samples of bryophyte mat extracted subsequently yielded an abundant micro-fauna of Collembola and mites, discussed by Tilbrook (1967*a*, *b*) (see p. 73–74).

Due to the steepness and heavily glaciated nature of the cliffs of the island, there are comparatively few nesting sites available for birds. The low projecting headlands have their penguin colonies and also support breeding groups of seal. On Finger Point there is a colony of about 5,000 breeding pairs of chinstrap penguins (*Pygoscelis antarctica*) together with a few macaroni penguins (*Eudyptes chrysolophus*). Skuas (*Catharacta skua lonnbergi*) were also found to be breeding on this headland. On the steep cliffs behind Finger Point there were large colonies of fulmars (*Fulmarus glacialoides*) and these colonies extend from this point westward around the island past Wordie Point as far as Mikhaylov Point. The colonies are not continuous as the terrain is not always suitable but wherever the ice falls give way to rocky ledges fulmars are to be found. Between Mikhaylov Point and Wordie Point there were a few cape pigeons (*Daption capensis*) nesting among the fulmars but none of this species was seen elsewhere about the island. There is a small colony of chinstrap penguins containing about 2,000 birds on Mikhaylov Point. Fulmars were also found to be nesting on the cliffs above Coffin Rock, at Saddle Bluff, and on the small unnamed outcrop just north-west of Saddle Bluff and seaward from Shamrock Hill.

On Irving Point there is another chinstrap colony in amongst which macaroni penguins make up about 10 per cent of the total as at Finger Point. This colony extends from the flat beach quite a long way up the rocky slope behind it. Separate from the main colony there is a small group of about 200 gentoo penguins (*Pygoscelis papua*). On Irving Point there were about 50 skuas and 50 gulls (*Larus dominicanus*), and about four or five pairs of both are thought to breed. It is difficult to be precise because the area was visited too late in the season.

Other birds seen but not found to be breeding were giant petrels (*Macronectes giganteus*), of which about ten were present around Finger Point, and Wilson's petrels (*Oceanites oceanicus*) were also seen in the same area. It is quite possible that this latter species does breed but no nests were found in the places visited. Two gentoo penguins were seen at Finger Point but none was breeding in this area.

When a party from *Protector* landed on the beach near Irving Point in January 1960, they found about 400 fur seals in occupation. Photographs taken on this occasion show harem bulls, cows and black-coated pups, and confirm that this was a breeding beach. In March 1962, no landing could be made but a photograph taken from a helicopter at about 330 m. allows a rough count to be made of the seals, which were abundant at the time. A total of 550 animals has been suggested by Holdgate (1963), and the photograph also recorded about 40 elephant seals. In March 1964, seal counts were made on the ground at Finger Point and Irving Point. In the first area there were two elephant seals hauled out and a single Weddell seal on the small beach on the north side. One juvenile fur seal was seen wandering among the penguins. Three leopard seals were swimming in the sea and periodically taking a returning chinstrap penguin.

The main colony of fur seal, and the largest seen in the South Sandwich Islands group, was present at Irving Point. In March 1964, the colony was quite extensive and spreading along most of the beach, although the majority of the animals were found in and around the small rock pools at the north-east end of the point. A census gave a total of 878 animals, of which 538 were pups and 25 were adult males. The pups were all well grown and mostly moulting, making it difficult to distinguish them from the yearling animals which were quite abundant. Many of the pups, although moulted, were still suckling and many of them had formed nurseries and were wandering about among the penguins on the slope behind the beach.

Apart from the fur seal, there were also 55 moulting elephant seals at Irving Point; these were animals of all sizes but mainly younger males of the 3–5 year class. Under the ice cliff to the north of Irving Point were three very flattened elephant seals surrounded by large blocks of ice, and these animals had obviously been crushed to death by an ice fall.

There was a further group of fur seal at Mikhaylov Point but it was not possible to land and the observations were made from a helicopter. Altogether there were about 100 animals and it is thought that there were a few pups among them, although the majority seemed to be juvenile non-breeding animals.

D. Candlemas Island

1. *Topography*

Candlemas Island (Fig. 8) has a more complex and diverse topography than most of the islands in the South Sandwich Islands group, but this intricate landscape is also one of the best known in the group because of the relatively long period for which a scientific party has lived ashore, and because of extensive air photography. It has been more closely studied by geologists and biologists than any other member of the archipelago and will therefore be treated at rather greater length here.

Candlemas Island is of irregular shape, aligned with its long axis running from north-west to south-east. In this direction, from Vulcan Point to Shrove Point it measures 5·7 km., while at its greatest width, from Sarcophagus Point to Demon Point it measures 3·1 km. Topographically, however, the island is divided into two entirely different parts linked (near the widest part) by an expanse of low flat sand; the continuity of this link, moreover, is reduced by two large lagoons.

The northern part of Candlemas Island is actively volcanic and probably of no great age. It consists of a roughly circular mass of lava flows, which surround a group of scoria cones. Around about two-thirds of its perimeter, this northern mass falls to the sea in vertical lava cliffs; in detail the coasts are highly irregular with a sequence of projecting rock fingers interspersed by recesses, clefts and small bays. Passing northward from Seaserpent Cove, where the northern lava complex first meets the open sea on the west coast, a fingered fan of lava of this kind forms the cliffed shore for 1·2 km. North of this, the coast swings eastward in a small bay, Tow Bay, whose other flank is formed from two lava flows thrusting out towards Vulcan Point. In the head of Tow Bay there is a boulder beach which separates off a pool of hot and steaming water, Cauldron Pool, immediately below the base of the main active cone. This hot pool was commented on first by Kemp and Nelson (1931), who spoke of it as "another large crater with its mouth little, if at all, above sea level". Its true nature was invisible to them from the sea, and they were unable to land and investigate.

East from Vulcan Point, which is the north-western extremity of the island, the coast curves back in another small bay with a patch of sand and boulder beach at its head. The rounded lobe of lava walling in this bay on the east terminates in the northernmost point of the island which has no name. To its east again, moving south-eastward along the coast, the cliffs girdling this lava flow fall back to form the wall of a narrowing gully, Clinker Gulch, containing two small pools. Of these, the seaward, which lies immediately behind a fairly broad boulder beach, is aligned parallel to the shore, but behind it the gulch narrows and is nearly blocked by an isolated pinnacle of rock, and the upper pool is elongate along the gully. On the east of the upper pool is a beach of black sand, and smooth, apparently wave-worn rocks flank it, suggesting that this side of the gully may be an old coastline now separated from the sea by the eruption of more recent lava flows. The gully terminates at the base of scoria slopes falling from the main cone.

East from Clinker Gulch, the coast runs almost directly south-eastward into the broad bay of Kraken

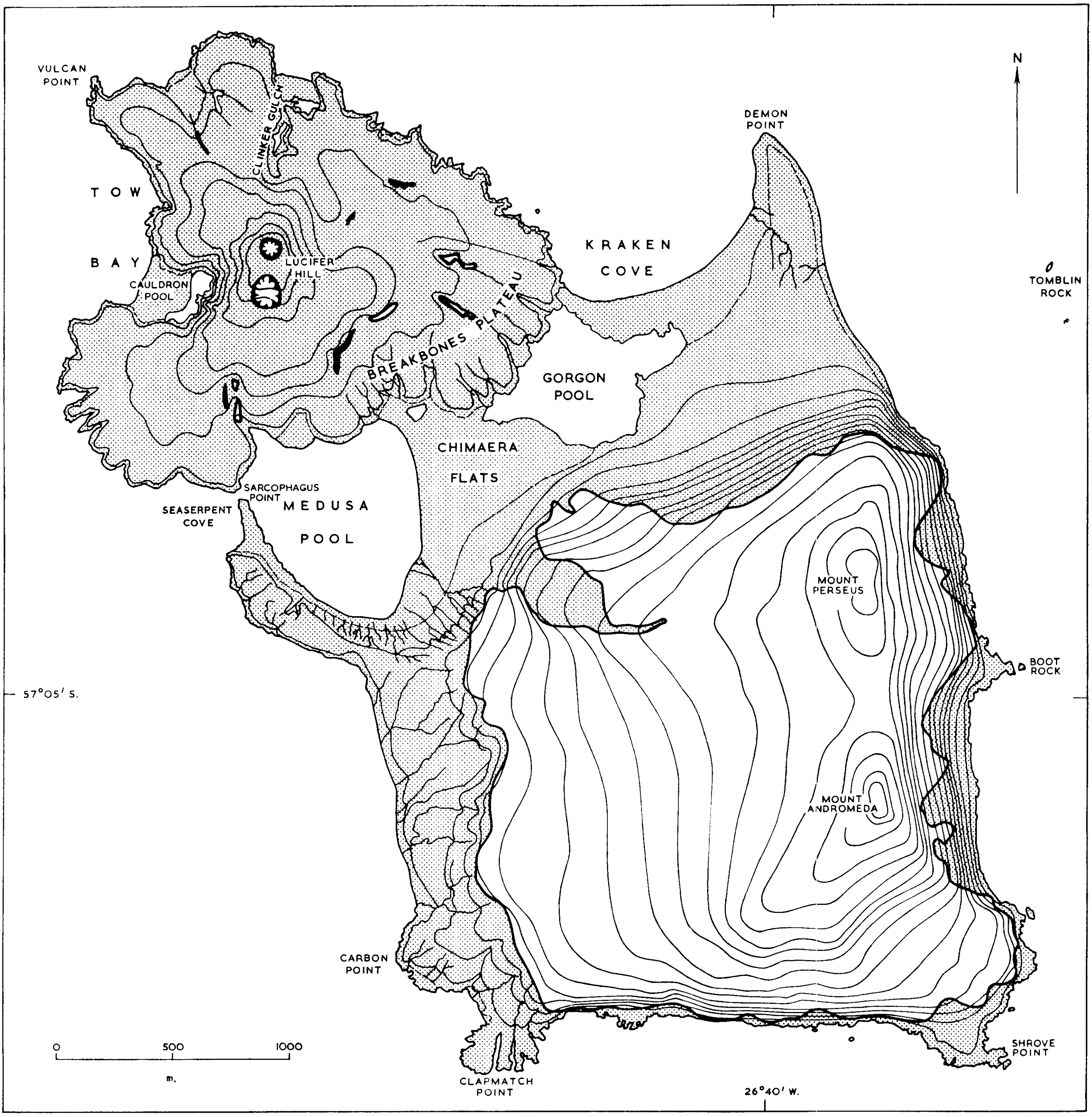


FIGURE 8
Sketch map of Candlemas Island.

Cove. All along this 1·5 km. stretch of cliff the detailed configuration of the shoreline is intensely serrated, small rock headlands alternating with clefts and bays, the latter occasionally backed by tiny beaches of piled boulders or sand. Only when the head of Kraken Cove is reached comes an abrupt contrast, the lava cliffs abutting on a spit of boulder and shingle which curves around the bay to the jutting, low north-eastern headland of Demon Point. Where they give way to a shingle bar in Kraken Cove, the lava cliffs girdling the northern part of Candlemas Island swing south and then progressively more to the west, forming a curve subdivided by alternating headlands and recesses just like the outer coast. This series of cliffs, however, falls not into the sea but into the calm and shallow waters of Gorgon Pool. West of this, a small embayment in the lava edge walls in the end of the central isthmus, Chimaera Flats, linking the two halves of the island and then a further series of indented lava cliffs flanks Medusa Pool. This particular series, with those overlooking Chimaera Flats, are more weathered than most about the northern half of the island, and they are partly edged by debris. Near the mouth of Medusa Pool, however, after trending westward past a recess filled by a fan of detritus, these cliffs give way to younger lava which meets in turn the flow walling the northern side of Seaserpent Cove so completing the perimeter of the northern mass of Candlemas Island.

The interior of this northern section of the island is largely formed by the irregular surfaces of the various lava flows spreading from the eruptive centre. On the north and west, and close against the south flank of the cone, these surfaces are extremely rough, being made up of broken unstable jumbles of fragments which are most laborious to traverse. On the east, however, especially between Clinker Gulch and Gorgon Pool, the lava surface is smoother and more obscured by scoria, and forms a plain, Breakbones Plateau, which is fairly easy to walk on, except near the coast. This platform is dissected by a few deep gullies and its surface is dotted with small and only slightly active fumaroles and patches of warm ground, made conspicuous by the vegetation mats surrounding them.

The central complex of scoria cones rises almost in the exact middle of the northern half of Candlemas Island. The main summit, Lucifer Hill (232 m.), is a simple cone of reddish cindery fragments, contrasting strikingly with the black lavas which lap its base, and it is surmounted by a small crater; a second shallow bowl of a crater is scooped out of its south flanks. Above Chimaera Flats the flanks of Lucifer Hill fall directly into Cauldron Pool, where they are covered by sulphurous deposits through which copious vapours escape. To the south-west, between Tow Bay and Medusa Pool, the main hill is flanked by two knolls having the appearance of minor cones and referred to as such by Kemp and Nelson (1931).

From any appreciable distance east or west, Candlemas Island appears to be two separate land masses (it was described as such by Bellingshausen in 1819). This impression is caused by the low-lying nature of the connecting land, which is also highly discontinuous. From Seaserpent Cove on the west, a narrow channel, partly bisected by a shingle spit running north from Sarcophagus Point, communicates with Medusa Pool which is consequently tidal. This lagoon, 750 m. in diameter, might be entered from the sea by small boats at high tide in calm weather, although its mouth is much obstructed by boulders. It is shallow especially on the east and south sides. Beyond the lagoon, the sand isthmus of Chimaera Flats narrows to only 325 m. near the northern lava cliffs. These flats may be washed over at extreme high storm levels; in 1962 and 1964, spars lay in places on their surface, perhaps originating from sealing expeditions. East of the flats, the second lagoon, Gorgon Pool, has a maximum length of 900 m. and is 600 m. wide at its widest, and in turn it is separated from the sea at Kraken Cove by a bar of sand and shingle only 75 m. across. Although the overall width of Candlemas Island in this central belt is 1·75 km., only 400 m. of this width is dry land, and none of that more than 5 m. above sea-level.

The southern mass of Candlemas Island is larger than the northern and it is more than twice as high. In outline it is roughly quadrilateral, the corners being formed by Demon Point, Shrove Point, Clapmatch Point and Sarcophagus Point. The east side between the two first-named points is the longest and extends about 4 km.

Demon Point, in the north-east of the island and at the northern extremity of the main mass, is a long low-lying headland with a flat top covered by debris and penguins, jutting almost 1 km. north from the base of the main mountain mass. Its basal levels merge with the eastern extension of Chimaera Flats and terminate beneath the towering rock cliffs that rise about 350 m. to buttress Mount Perseus. These cliffs run to the coast 1·25 km. south from Demon Point and swing round to continue the south-south-eastward trend of the shore, falling sheer into deep water. Offshore about 0·75 km. from this point is the isolated conical mass of Tomblin Rock.

The eastern coast of Candlemas Island consists for the remainder of its length of high rock cliffs down which spill two main masses of ice. The first of these descends almost to the shore just north of a rocky headland jutting out to the detached lump of Boot Rock. The second glacier spills down as an apron of ice immediately beyond the high east wall of Mount Andromeda and before the coast falls to the shelving rocky headland of Shrove Point. Shrove Point itself is only about 30–50 m. high and projects about 300 m. from the foot of the ice-capped main slopes, and passing west from it along the south coast of the island the cliffs steadily increase in height again and are capped by overhanging ice. Clapmatch Point, at the south-west corner of the island, is also a place where the coast again becomes lower and where the ice cliffs terminate in morainic knolls and then give way to lava flats. Clapmatch Point is formed of a lava flow, the main surface of which is less than 30 m. above the sea, and which pushes out five radiating fingers of rock separated by narrow clefts. Passing north-westward from this point, the coast recedes into a small bay with a shingle beach and then projects in a rounded shoulder, Carbon Point. From here the coast runs straight in banded cliffs about 30 m. high to the base of the northward-jutting narrow promontory of Sarcophagus Point.

Only the western and northern lowlands of southern Candlemas Island are ice-free. In the north, the levels of Chimaera Flats slope upwards to the south of both lagoons and abut against a series of flat-topped knolls whose northern faces together compose a curved bank running from the base of Sarcophagus Point right across the island to the cliffs above Gorgon Pool. This regular bank may represent an old shoreline. Above it, the flat-topped knolls, dissected by gullies running from the ice cap and carrying melt streams in summer, abut on the bases of the steep cliffs and ice slopes descending from the main mass of the island. It was in one of these gullies that a sheltered camp site was found in March 1964. The cliffs of rock and ice above them mount steeply for about 250–350 m., and then more gently as they give place to the slopes of the upper ice cap.

On the west, the flat-topped ridge running back from Sarcophagus Point forms the northern limit of a plain which extends about 1 km. to Carbon Point. In the north this plain is 300 m. wide; it tapers southward as a line of rounded steep-sided hills swing out from below the ice cap towards the sea at Carbon Point. The plain is traversed by narrow gullies cut by melt streams running from the ice cap, and in places these cascade over rock lips where they fall from the knolls above. These knolls mount to the edge of the ice cap, where a prominent moraine marks the transition to the even crevassed slopes that rise eastward to the summit ridge.

The summit ridge of Candlemas Island lies well to the east of centre, very close to the east coast. It is orientated due north–south and is capped by two peaks. Mount Perseus, the northern and lower summit, has a double crest which attains about 455 m. and is covered on the north, west and south by steep slopes of broken ice but on the east and south-east it falls away in rock cliffs towards the sea. Mount Andromeda, the southern and higher summit, attains 550 m. in a single ice-capped ridge.

The extensive ice cap of Candlemas Island covers about one-half of the total surface of the island. Its lobes on the north fall as steep but minor glaciers and terminate with small moraines; its eastern and southern faces cascade direct to the sea. On the west, the long sinuous ice foot is flanked by extensive moraines which have probably contributed to the debris cover of the ice-free coastal lowlands in this area. Attempts were made in March 1964 to record temperatures at various depths in holes drilled on the Candlemas Island ice cap, and stakes were set up as future reference points. By analogy with Vindication Island, which would seem to have no more history of recent activity than this part of Candlemas Island, it is suggested that this southern section of the latter island indicates fairly well the minimum conditions of area and height required for ice to accumulate in this part of the South Sandwich Islands group. On Candlemas Island there is about 1·5 km.^{2} of surface above 300 m. and a maximum altitude of 550 m.; the result is an extensive ice cover descending on the inland side to between 50 and 100 m. in places. On Vindication Island there is only about 0·6 km.^{2} of land above 300 m. and a maximum elevation of 450 m.; the result is a small and shrinking apron of ice above the 250 m. contour.

A rough sketch survey of Candlemas Island was made by Larsen in 1908 but the outline given cannot readily be reconciled with the terrain, probably because Larsen was ill at the time and spent no longer on deck than necessary. The first careful survey was made from *Discovery II* in 1930 and this was supplemented by detailed maps of the shores of Tow Bay and Seaserpent Cove. There are conspicuous discrepancies between these maps and the present terrain and, in view of the details especially on the charts of the two coves, it seems possible that some at least of these result from volcanic activity since 1930. These are discussed in greater detail below. It is less easy to evaluate the causes of the discrepancies between the present terrain and the representation on an inset to Admiralty Chart 3593 (1960 corrections, incorporating information supplied by J. R. H. Huckle in 1957). This inset shows for the first time the lagoon of Medusa Pool, but it fails to indicate its link with the sea and misplaces it in relation to other land features. The present maps are based on vertical air photography in 1962 and 1964, covering most of the coastline and almost all the northern half of the island, supplemented by oblique air photographs of the remaining area.

Ground control is provided by a local triangulation with distance measurements by tellurometer. The position of the island was determined by star sights.

The first recorded landing on Candlemas Island was by C. A. Larsen in 1908. However, in 1964, spars and a shafted blubber hook were found ashore, suggesting that sealers, known to have been operating in the group in the nineteenth century (Allen, 1899), may have previously lived ashore. A second landing by boat was made from *Shackleton* in 1960 near Seaserpent Cove, and in March 1962 a helicopter from *Protector* landed a party on Chimaera Flats. These flats and the even-topped knolls south of Medusa Pool were again the main landing place for helicopters in March 1964, but the top of Sarcophagus Point, part of Breakbones Plateau and a knoll inland from Carbon Point were also used. Candlemas Island abounds in suitable helicopter landing places, although local turbulence may make a close approach to the southern ice cap dangerous when the wind is between east and south.

2. *Geology*

The geology of Candlemas Island is discussed in detail in a separate publication by Tomblin (1979).

Candlemas Island is divided both geographically and geologically into two distinct parts: namely an older, volcanically extinct southern massif; and a younger, recently active northern volcanic centre.

Southern Candlemas Island is largely ice-capped but rock exposures of porphyritic basalt lava flows alternating with scoria layers occur around the margins. The westerly dips of the lava flows, which increase from a few degrees near the west coast to a maximum of about 30° at the eastern side of the island, indicate that the flows were probably erupted from a vent beyond the present eastern coastline, and that only the western side now remains of the volcano from which they were erupted. The youngest looking geomorphological features in southern Candlemas Island are two lava flows at the south-western corner of the island, which appear to have been emitted through vents near sea-level.

Northern Candlemas Island consists of a central scoria cone surrounded by lava flows which have issued from several vents around the flanks of the cone. The lava flows form a series of broad overlapping terraces, the surfaces of which are inclined gently seawards. The lavas and scoria of northern Candlemas Island consist of almost aphyric andesite. The initial eruptions from the northern volcanic centre probably took place beneath shallow sea-water, following which a scoria cone was built up above sea-level. This cone appears to have grown to at least 190 m. above sea-level before the beginning of effusive activity, since the earliest flow in the sequence now visible crops out at this elevation. Subsequently, a large volume of lava was emitted from the eastern flank of the scoria cone to form the east and north-east lava flows. The next activity involved the vertical ejection of ash and scoria, in four episodes, to form four layers mantling the east and north-east lava flows.

A subsidiary conelet then grew on the south-western flank of the scoria cone, from which the south-west lava flow was emitted. This flow is overlain by a single ash and scoria layer, which also forms a fifth pyroclastic layer on the east and north-east lava flows.

Two lava flows in northern Candlemas Island form particularly young-looking features and have no mantle of pyroclastics. The south lava flow, which appears to have been the earlier, issued from the southern boca and flowed in two lobes, to the east and to the south-west. The youngest lava flow on Candlemas Island lies in the north-west; this is a composite unit comprising at least four overlapping lava tongues, which issued consecutively from the northern boca. The most recent lava tongue is still emitting steam from many points at its surface and it could possibly be the flow which was reported to be glowing by *John Biscoe* in 1953–54 (Holdgate, 1963, p. 401) but the validity of this observation is questionable.

The earliest report of volcanic activity at Candlemas Island was provided by Morrell (1832), who spoke of "two burning mountains, the lower and westernmost of which was almost level with the water". It is impossible to reconcile his account with the present terrain and there can be no question that Vindication Island was the low western "burning mountain . . . almost level with the water", since Bellingshausen's excellent engraving, produced only 3 years earlier, shows both this island and the southern part of Candlemas Island looking much as they do today. Neither Bellingshausen nor Cook recorded volcanic activity in the group and the earliest reliable description, itself not without inconsistencies, was provided by C. A. Larsen in 1908. Larsen's sketch map is quite irreconcilable with the present form of the island but it agrees broadly in showing a northern active part, rising above a lava plateau, and a southern ice-covered mass linked to the active part by a waist.

Larsen's account and map are remarkable for their description of a broad bay, fringed by sunken rocks, on the east side of Candlemas Island. A boat, sent inshore, found 5 fathoms [9·5 m.] at the shallowest point, and an excellent harbour for small boats inside the rocks. It is difficult to discount this circumstantial detail and it is tempting to speculate that at the time of Larsen's visit perhaps the shingle spit now extending from the northern lava plateau to Demon Point around Kraken Cove had not formed, so that the eastern lagoon, Gorgon Pool, opened to the sea. Such an interpretation would fit with Larsen's sketch chart, since his eastern bay has the form and situation of Gorgon Pool.

There are also interesting discrepancies between the charts made during the visit of *Discovery II* and the conditions prevailing today. In 1930, *Discovery II* found no trace of Larsen's eastern bay and recorded Demon Point as a narrow bifid structure terminating a shallow curving embayment. There can be no doubt that at this date Gorgon Pool did not open to the sea, but it is likely that Demon Point genuinely differed in form from its present blunt rounded protrusion. On the other side of the island too, in the vicinity of Seaserpent Cove, where a detailed sketch plan was made, there are suggestive comments. A boat from *Discovery II* came close inshore in the cove and mapped the end of Sarcophagus Point and the lava flow opposite in a way readily fitting with the present situation. However, they recorded a continuous low platform of lava and boulders extending across the head of the cove from one side to the other. The boat came close enough inshore to see round behind the corner of Sarcophagus Point, and it seems incredible that from the position reached (only 100 m. away) the channel linking Medusa Pool to the sea was invisible, if in fact it existed at that time. A "low plateau, 8–12 ft. [2·5–3·8 m.] above sea level" was marked extending behind the beach right across the head of the cove.

In 1927 and 1930, actual volcanic activity on Candlemas Island was much as it is today. The northern cone was emitting vapour, and steam was seen rising from the base of the cone from a point coinciding with the present steaming lakelet, Cauldron Pool. Since regular puffs of steam were noted in this area, it is possible that the group of small geysers active in 1962, but not in 1964, was present. Similar emission of vapour was seen in 1953, 1955, 1956, 1961 and 1962. Although the observation of glowing lava from *John Biscoe* in 1953–54, cited by Holdgate (1963) has been questioned, it seems likely that some, at least, of the northern lava flows have been emitted in the period since 1930.

In March 1962, judging from photographs, there was rather more steam emission from the main cone than in 1964. Holdgate (1963) also described several geysers, the largest of which sent a jet to a height of 3–4·5 m. on the scoria slopes above Cauldron Pool. These were not observed in 1964. Fumaroles on Breakbones Plateau and on the lava flows above Medusa Pool were observed in 1962 and 1964, and showed no significant difference in vigour in the 2 years; they were not as active as those on Bellingshausen or Leskov Islands.

No volcanic activity of any kind has been observed in the southern half of the island.

3. *Vegetation and fauna*

The vegetation of Candlemas Island is greater in extent and richer in species than on most islands of the group, and was the subject of detailed survey by R. E. Longton (Longton and Holdgate, 1979). On the northern part of the island, substantial bryophyte mats surround fumaroles on Breakbones Plateau, and in the area just north of Medusa Pool there are patches of the grass, *Deschampsia antarctica*, which is not known elsewhere in the South Sandwich Islands group. Away from volcanic warmth and moisture, on the southern part of the island, there are also considerable moss mats and numerous lichens. All these vegetation types, and some areas of apparently plant-free soil, support numerous invertebrates (mites, Collembola and nematodes), which have been studied in detail by Tilbrook (1967*a*, *b*). Bird parasites are also occasionally encountered among vegetation and soil.

The avifauna of the island is extensive. Larsen (1908) first recorded breeding chinstrap (*Pygoscelis antarctica*) and Adélie penguins (*Pygoscelis adeliae*) when he landed in November 1908. The main penguin colonies are situated on the edge of the lava flows north of Medusa Pool, on the spit below Sarcophagus Point and beside the lagoon on Demon Point, at Shrove Point, on Carbon Point and on Clapmatch Point. About 75 moulting macaroni penguins (*Eudyptes chrysolophus*) were present among the chinstraps in the last-named area in March 1964. Gentoo penguins (*Pygoscelis papua*) were found in sheltered spots in the northern lava fields, about 550 birds being seen altogether. Breakbones Plateau is the site of a large breeding colony of giant petrels (*Macronectes giganteus*) totalling perhaps 130 nests, while other groups of this species breed on the knolls west of the main ice cap above the coastal plain which extends from Sarcophagus Point to Carbon Point. The total number of nests estimated in March 1964 was of the order of 520. Cape pigeons (*Daption capensis*) and fulmars (*Fulmarus glacialoides*) probably breed on the cliffs of the southern half of the island, and snow petrels (*Pagadroma nivea*) undoubtedly occur. Brown skuas (*Catharacta skua lonnbergi*) breed on both the western slopes and in the northern part of the island; fledged young were seen in 1962 and 1964. Wilson's petrels (*Oceanites oceanicus*) were seen over land in 1964 and nests found in the ash south of the craters. Shags (*Phalacrocorax atriceps*) were seen twice at Clapmatch Point.

On Clapmatch Point, a small breeding colony of fur seal (*Arctocephalus gazella*) totalling 601 individuals was found in March 1964. Of these, 294 were pups and 41 were adult males. The pups on Candlemas Island did not appear to be as fully grown as those on Visokoi Island; fewer had completed their moult and they had not left the harem groups as much as those on Visokoi Island. Also, the proportion of pups to adult cows was less, which indicates that the seals on Candlemas Island had perhaps been born a little later; in turn, this might indicate that Candlemas Island is used as an overspill breeding area when Visokoi Island is "full".

Moulting elephant seal (*Mirounga leonina*) were hauled out about the two lagoons and Kraken Cove in 1962 and 1964. Weddell seal (*Leptonychotes weddelli*) were seen ashore in the same area in both years, and leopard seal (*Hydrurga leptonyx*) were seen ashore on the isthmus between the two lagoons, as well as at Clapmatch Point. Leopard seals were frequently seen in the sea near penguin colonies and one was filmed taking returning birds. There is no evidence of breeding of any species other than the fur seal, although the area appears suitable for an elephant seal colony.

E. Vindication Island

1. *Topography*

Vindication Island (Fig. 9), the smaller of the two Candlemas Islands, lies only 4·5 km. to the west of its neighbour across the channel of Nelson Strait. The two islands are partly linked by a belt of shoals running east from Braces Point through Trousers Rock. Vindication Island rises amidst a series of off-lying rocks and islets which extend farther from the shore than is usual in the South Sandwich Islands group.

Representations of Vindication Island on the charts have ranged from a pentagonal form to one in which a deep embayment was plotted on the west coast. Vertical air photographs taken in March 1964 indicate, however, that its outline is a rather regular, nearly rectangular, parallelogram whose angles face the principal points of the compass. The two long sides, on the north-west and south-east, are about 2·1 km. in length, while the shorter south-eastern and north-western sides are 1·6 km. long. The longest diagonal across the island, from Crosscut Point in the north-west to Chinstrap Point in the south-east is 2·8 km. in length. The summit, which rises immediately above Knob Point at the western angle attains a height of 442 m. The island is remarkable for the continuity and steepness of the high rocky cliffs which surround it.

Although in detail the relief is complex, in general the surface of the island slopes fairly consistently from the highest point in the south-west down towards the northern and eastern coasts with the gradient tending to decrease away from the summit of the island. The sharp ice-covered ridge forming the summit of the island is separated by a broad trough about 131 m. wide and about 15 m. deep from a second and slightly lower peak above Knob Point. It is possible that the crest of the highest ridge follows the rim of an old crater, of which the trough itself may be a relic.

The northern point of the island, Crosscut Point, is a most conspicuous cluster of towering rock spires. About 200 m. offshore is an islet about 100 m. long and a similar distance across with a flattish top surmounted by two pinnacles at its landward side. Next inshore, and separated from the mainland by a narrow channel 25 m. across, is a mass of rock of similar size culminating in a conical crest about 75 m. high. Inshore again, the main spine of the headland is capped by a third tower of "sugar-loaf" form, rising to a little over 100 m. This complex of rock pinnacles forms but the lower part of a serrated ridge which rises abruptly to a subsidiary peak at the northern end of the main island. This summit, Splinter Crag, attains about 175 m. and is triangular in profile from all angles; on the north and west it falls in sheer coastal cliffs, while on the south-east its third face descends more gently into a small hanging valley.

Passing south-eastward from Crosscut Point, the coast runs straight (the long north-east face of the parallelogram) to a shingle spit, Braces Point, jutting towards Trousers Rock. Only one small rock projection, about 600 m. before Braces Point is reached, breaks the uniformity of the shoreline and this is of no

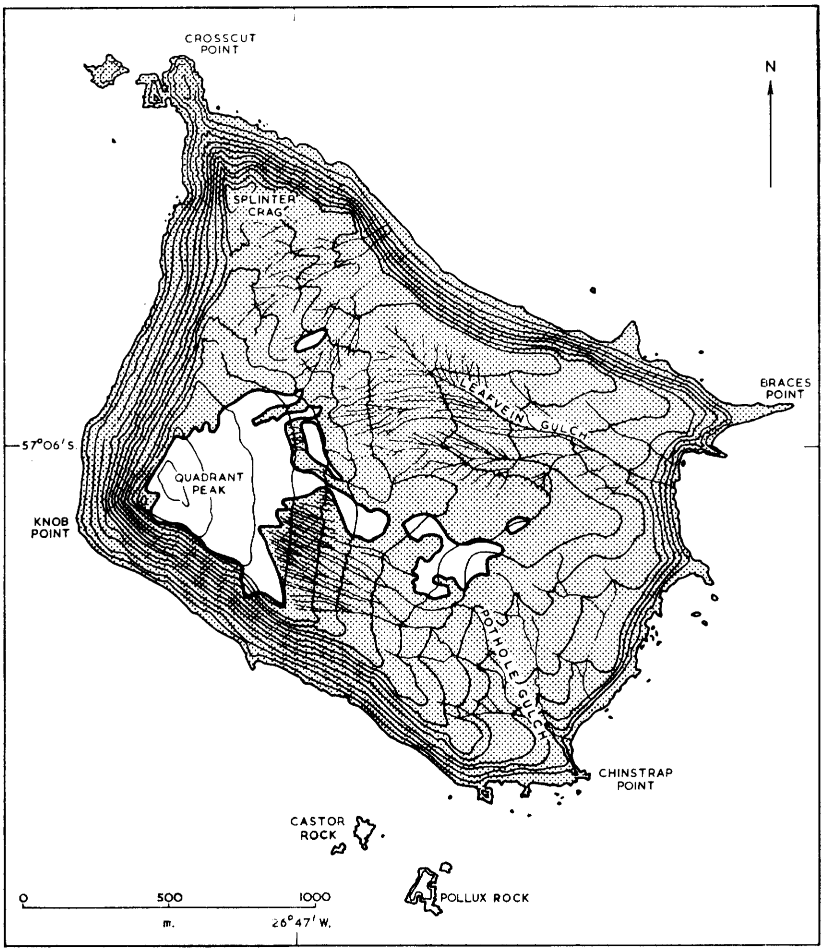


FIGURE 9
Sketch map of Vindication Island.

great height extension. Above this uniform coastline and its narrow fringing boulder beaches, the cliffs, which are strikingly banded with black lava and reddish tuffs cut by dykes, are of uniform height (about 200 m.) but they slant steadily downwards over the last 500 m. towards Braces Point, above which they are only about 75–100 m. high. The spit of Braces Point itself is probably awash in storms but under normal conditions it extends about 200 m. east from the cliff base; it is about 50 m. wide at its base and tapers to a sharp apex.

The south-east coast of Vindication Island is both lower and more varied than the north-eastern one. Adjoining Braces Point is a small cove flanked to the south by a narrow wall of rock formed by a projecting dyke. This in turn is succeeded by a longer cove backed by a boulder beach below 200 m. cliffs, down which a waterfall from the main drainage valley on the northern half of the island cascades in summer. To the south, the cove is flanked by a nose of cliffs above a small low-lying rock point, and thereafter a belt of rough boulder beaches with many off-lying rocks extends, interrupted by occasional projections of cliff, to Chinstrap Point in the southern corner of the island. Along this run of coast the cliffs descend steadily and are set back from the beach by a broadening talus slope; just before Chinstrap Point they are broken by a gully carrying the main drainage stream from the southern half of the island. The mouth of this gully is the only place around the whole perimeter of the island at which the slopes of the land descend to the coast without any intervening cliff.

Off Chinstrap Point to southward there is a belt of rocks and blinders, and passing westward there is a fairly broad boulder beach extending about 300 m. to the base of a large, nearly isolated, mass of rock about 25 m. high around which the sea probably washes in storms. From this rock stack the coast bends more to the north-west and runs rather straight with but one small interrupting promontory to the high cliffs at Knob Point. This section of coast, the second long side of the parallelogram, is characterized by a narrowing of the beach as one goes west and its replacement first by a steep boulder slope and then by unobscured cliff bases. The cliffs rise steadily in height from their beginning at Chinstrap Point to a maximum of 425 m. at Knob Point, the highest and most sheer section of the entire coastline of Vindication Island. These cliffs, like those on the north-east coast, are of conspicuously stratified lavas and tuffs, and at the western angle they fall unbroken from the summit of the island to the sea.

Rounding Knob Point, a similar towering, precipitous banded range of cliffs runs north-eastward to Crosscut Point, dipping slightly to the col between Quadrant Peak and Splinter Crag, but nowhere falling below 300 m. Seen from the sea or air, Vindication Island appears as a fragment of about one-third of a volcanic cone. The highest summit of the island, Quadrant Peak above Knob Point, is flanked between north and south-east by gentle slopes which contrast strikingly with the savage cliffs on its other sides. These gentle eastern slopes, which are probably part of the original flank of the volcano, descend steadily to the crests of the cliffs by which they are truncated. The surface of the island is thus an inclined tableland dipping to the east, and somewhat diversified by ridges, erosion gullies and minor irregularities. One drainage system, cut back so that only three separate hanging valleys all less than 400 m. long now remain, runs from the hollow between Quadrant Peak and Splinter Crag to the north-east coast. The fact that these valleys appear to have commenced in an area well to the west of the present summit suggests that the island was formerly much larger in area than at present and that it has been severely truncated by marine erosion.

The second major system, Leafvein Gulch, begins just below the base of the small Quadrant Peak ice cap at about 300 m. and descends in a shallow valley about 450 m. across and 1·2 km. long to the edge of the cliff south of Braces Point. Between Leafvein Gulch and the north-east coast there is a low and rounded ridge cut away abruptly along its crest by the coastal cliffs, and a similar but not truncated ridge forms the southern flank of the valley. This ridge descends from the foot of the Quadrant Peak ice cap in a series of undulations interspersed by small platforms, one of which, near the centre of the island, proved the best helicopter landing place in both 1962 and 1964. The ridge broadens as it descends into a series of rather featureless hummocks above the middle of the south-east coast.

The third valley system of the island, Pothole Gulch, drains a broad area between this central ridge and a minor ridge along the south-west coast. In its upper parts, the hollow is fed by a number of narrow and shallow gullies falling from the ice cap, but lower down the drainage is less regular, consisting of many streams, most of them in V-section gullies which wind their way around knolls and between minor ridges. Some of the stream beds cut into soft tuff contain deep swallow holes. All except one of these streams, which drops over a waterfall about 100 m. farther east, converge to the gully opening on the beach near Chinstrap Point.

There is a very small ice cap on Vindication Island. It covers the upper parts of the south and east flanks of Quadrant Peak and actually forms the summit ridge. On the north-west it is sectioned by the coastal cliff and appears to be only about 20 m. thick; its western margin curves back above the cliff top over Knob Point and is about 25 m. high; on the south-west it is again sectioned by the cliff and, except for one small lobe, nowhere exceeds 50 m. in thickness. On the east its slopes are smooth and in March 1962 and 1964 these were bare of snow and gullied by ablation; it seems evident that at the present time the ice cap is shrinking. At its base about 90 m. below the summit of the island on the east there is a substantial moraine, and below this on the upper parts of the central ridge of the island and its southern flanks there are a few patches of old and probably permanent snow possibly marking a former extension of the ice cap.

Vindication Island was the subject of a running survey by *Discovery II* in 1930 (Kemp and Nelson, 1931) and its coastline was modified (for the worse) on Admiralty Chart 3593 (1960), following information received from J. R. H. Huckle in 1957. The present map, based on vertical air photographs from a helicopter, differs materially from all earlier representations. The height of the island, on the other hand, was reasonably correctly fixed by Kemp and Nelson at 1,395 ft. [425 m.]; in March 1962 sextant angles from *Protector* gave 1,420 ft. [433 m.] and a helicopter altimeter gave the present accepted figure of 432 m.

The first recorded landing on Vindication Island was from the Argentine vessels *Hercules* and *Sarandi* in 1951–52. In 1957, two landings by boat were made from *Shackleton*, the first near Chinstrap Point and the second on Crosscut Point. In 1962, a helicopter from *Protector* landed on the central ridge of the island and in March 1964 landings were again made both at this point, a small platform about 220 m. above sea-level on the ridge crest, and also higher up near the eastern base of the ice cap. The island is thus one of the most visited of the group. It is also one of the easiest to traverse on foot and in March 1964 almost the whole surface was covered. Access from the coast to the interior or vice versa is the most difficult problem in working on this island as this is easy only in the area around Chinstrap Point.

2. *Geology*

With the exception of the ice-covered areas, the surface of Vindication Island is strewn with blocky debris through which *in situ* lavas and pyroclastics appear in places. The oldest material is almost certainly to be found at the foot of the cliffs especially in the south-west. The lavas which protrude through the mantle of talus on the surface of the island are presumably amongst the youngest flows.

Sections exposed around the coast were observed from various vantage points on the cliff top; these are described first and are followed by an account of the geological features inland.

Along the west coast, between Crosscut Point and Knob Point, stratified lavas and tuffs dip eastward at about 30°. The upper part of the cliff at a small promontory about 400 m. north of Knob Point shows the following succession:

	m.
Lava	10·5
Red tuff	9
Lava	36

The cliffs at Knob Point consist of bedded red and yellow tuffs and lava flows, irregularly draped with snow and ice. On the cliff top, a brown ash containing blocks of basaltic lava occurs only a few centimetres beneath the surface of the ice. There are dykes at various places in the western cliffs but they are especially conspicuous at Crosscut Point in the north-west. The volcanic rocks at Crosscut Point are again red and yellow tuffs and lavas but here they tend to dip towards the south-east; a relatively fine brown ash forms the steeply dipping surface immediately inland from Crosscut Point. The rocks and sea stacks off Crosscut Point appear to be built mainly of columnar-jointed lava cut by dykes. Tuffs are preserved on some of the islets.

The eastern two-thirds of the north-east coast show another succession of lavas and pyroclastics but this time dipping at about 30° to the south-west. A typical section about 440 m. to the west of Braces Point shows:

	m.
Yellow tuff	6
Red tuff	6
Lava	3
Alternating lava flows, rubbly horizons and red tuffs	30

The yellow tuff at the top of this section thickens westward to a maximum of about 15 m. and wedges out eastward towards Braces Point. A porphyritic basalt forms a craggy pinnacle on the cliff top 180 m. to the west, and blocks of aphyric basalt are also found amongst the talus in the vicinity.

The following succession occurs in the cliffs 400 m. west of Chinstrap Point:

	m.
Lava	12
Scoria	6
Lava (wedges out towards Chinstrap Point)	3
Stratified tuff, ash and scoria	30
Lava	37

The uppermost lava, a plagioclase-pyroxene-olivine-phyric basalt, crops out over a considerable area for about 360 m. inland from Chinstrap Point where it is patchily covered by brown ash and lapilli. The basalt exposed in the low cliffs at Chinstrap Point itself is believed to be the lowest of the three lava flows seen in the above section. A conspicuous lava, which appears on the edge of the cliff between Knob Point and Crosscut Point, runs north-eastward down the slope to meet the north-east coast about 450 m. east of Crosscut Point; there appears to be a second and shorter branch to the same flow, commencing on the cliff top about 90 m. south of the larger one. The lava is pale grey to reddish in colour and contains abundant phenocrysts of plagioclase, pyroxene and olivine; its source evidently lay somewhere to the south-west of the present island. Another basalt lava crops out along, and is probably responsible for, the sinuous ridge trending north-eastward from the foot of the glacier across the central part of Vindication Island. The flow is a dark porphyritic basalt with conspicuous phenocrysts of plagioclase, pyroxene and olivine. Running southward from a point about half-way along this flow is another, apparently older, lava which is pale grey in colour but it also contains phenocrysts of plagioclase, pyroxene and olivine; it is similar in appearance to the flow south of Crosscut Point mentioned above.

There are three apparently conflicting elements in the present pattern of dips on Vindication Island:

i. Lavas and pyroclastics forming the bulk of the island dip to the north-east or east.
ii. At Crosscut Point the dip is to the south-east.
iii. Along most of the north-east coast the dip is to the south.

Collapse of the central part of the island and consequent reversal of some of the dips is unlikely to have occurred and such an explanation lacks supporting evidence. It is more likely that the material forming Vindication Island was derived from at least three independent but adjacent volcanic centres. The steep cliffs around the island and also the drainage pattern suggest that it was at one time considerably larger than at present and two of the three centres have probably been largely removed by erosion. The dips suggest that the main centre lay off Knob Point in the south-west and the parasitic centres were located to the north-west of Crosscut Point and off the north-east coast somewhere in what is now Nelson Strait.

There is no record of volcanic activity on Vindication Island and there is nothing in its vegetation to suggest the site of any former fumaroles. There seems no justification for Kemp and Nelson's (1931) conclusion that the lack of snow and ice cover denoted volcanic heat; it is considered that the island is too small and low for the formation of an ice cap under prevailing weather conditions and the shrinkage of the present small ice cap is taken as confirmatory evidence of this.

3. *Vegetation and fauna*

Despite the lack of fumarolic activity or warm ground, Vindication Island is one of the best vegetated in the South Sandwich Islands group. Moss patches are well developed locally on rocks surmounting the eastern cliffs above Braces Point and are more sporadic in wet hollows and on banks in the southern drainage basin. Lichen communities with some mosses are widespread on rocky crests on the central ridge. The alga *Prasiola crispa* characterizes drainage zones below bird colonies. The vegetation will be described by Longton and Holdgate (1979). As elsewhere in the group, the vegetation and soil yielded mites and Collembola in some quantity.

Vindication Island supports one of the largest colonies of chinstrap penguins (*Pygoscelis antarctica*) in the archipelago. This colony sprawls over the slopes of the south-eastern basin above Chinstrap Point where the birds enter and leave the sea and it covers a total area of about 360,000 $m.^2$ though not at uniform density. Various rough field estimates put the number of birds present in March 1964 at 60,000–100,000 but the upper figure may still be too small. In among the chinstrap penguins were small groups of macaroni penguins (*Eudyptes chrysolophus*) totalling about 100–200 birds. Wilkinson (1957), recording a landing earlier in the 1956–57 season, found snow petrel (*Pagadroma nivea*), cape pigeon (*Daption capensis*) and silver grey fulmar (*Fulmarus glacialoides*) breeding in large numbers on the cliffs above Braces Point, and in March 1964 *Daption* chicks remained on some nests, although they were almost fully fledged. Many (about 1,000) *Fulmarus* were flying about the cliffs and occupying ledges. These birds, with the penguins, probably comprise most of the avifauna but, in March 1964, skuas (*Catharacta skua lonnbergi*), Dominican gulls (*Larus dominicanus*) and Wilson's petrel (*Oceanites oceanicus*) were seen over the land and were probably breeders. One giant petrel (*Macronectes giganteus*) passing over the coast was likely, however, to have come from the nearby breeding colony on Candlemas Island.

A few elephant seal (*Mirounga leonina*) were hauled out on the beach near Chinstrap Point in March 1964 and leopard seal (*Hydrurga leptonyx*) were conspicuous in the sea offshore. However, in view of the small extent of suitable beaches, it is thought unlikely that the island supports many seals.

F. Saunders Island

1. *Topography*

Saunders Island (Fig. 10) is approximately in the centre of the South Sandwich Islands group. It is a broadly crescentic island, the concavity on the east forming the wide shallow embayment of Cordelia Bay. The northern arm of the crescent ends bluntly, while the southern limb tapers more sharply to the pronged headland of Nattriss Point. In overall length, from Harper Point to Nattriss Point, the island extends 8·3 km., while its greatest width, between Carey Point and Cordelia Bay, measures about 5 km. The summit of the island, Mount Michael, attains 990 m.

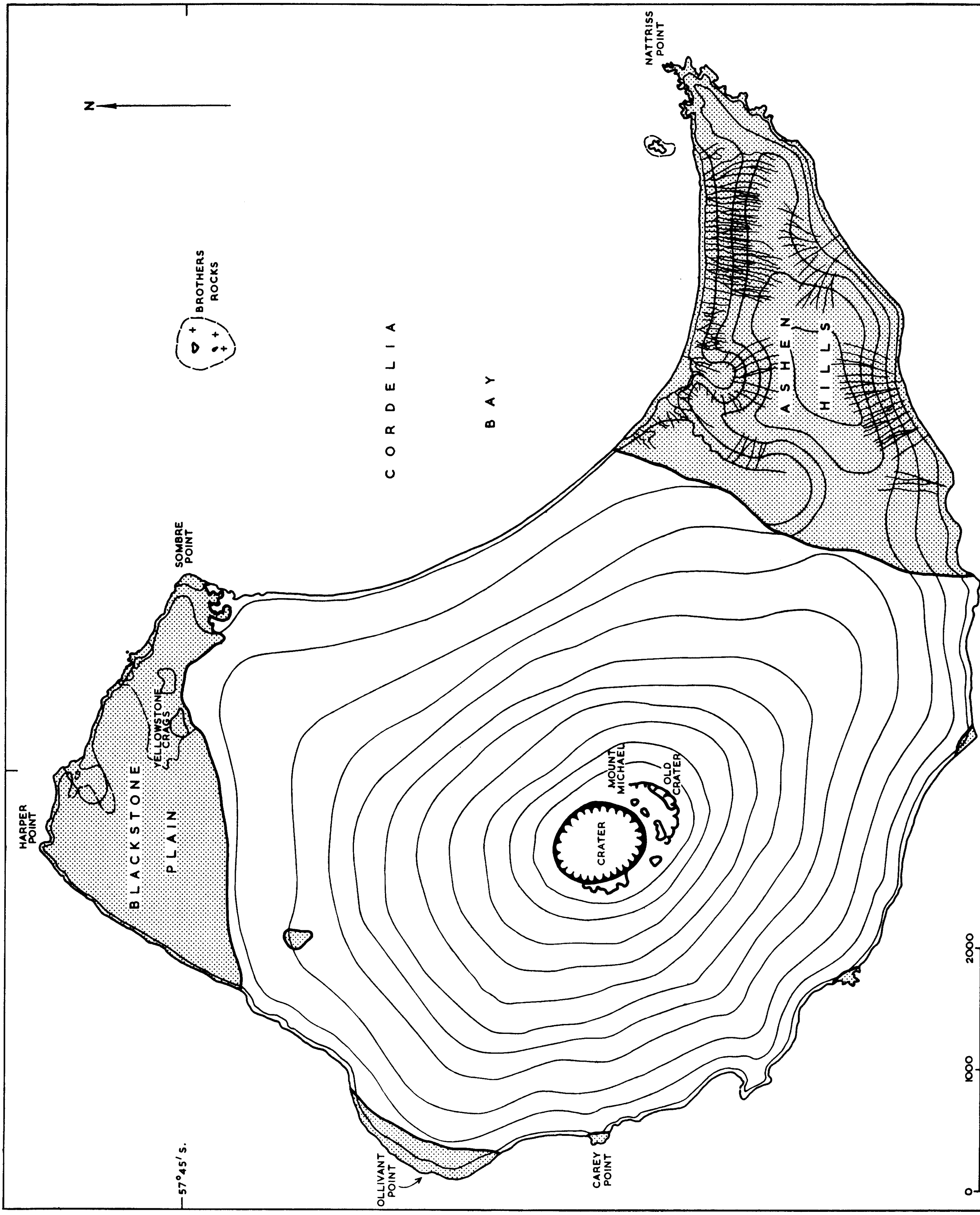
The northernmost point of the island, Harper Point, is the termination of a plateau of black lava, whose surface has a uniform elevation of about 30–50 m., and which is cut off around its perimeter by vertical cliffs of similar height. Passing south-eastward from Harper Point towards Sombre Point, this even cliff line is only locally broken by a few gullies and one or two depressions filled with black scoria, which run down to beaches of sand and boulders. At Sombre Point, where the lava cliffs are reduced in height and give way to a boulder beach, the coast turns sharply and runs south. After 400 m., however, the sand, boulders and snow overlying them near their southern end give way to the ice cliffs which terminate the glacier falling from Mount Michael. At this point the shore begins to swing increasingly eastward in a gradual arc and this curving coast, throughout composed of vertical or broken ice cliffs about 30–50 m. high, flanks the whole of what remains of the northern half of Cordelia Bay. Below the ice there is a beach of black sand over which the surf runs right to the cliff base and, because of this and the heavily crevassed nature of the glacier, this coast could not readily be traversed on foot.

The ice cliffs of Cordelia Bay end after about 3·5 km., giving way to a broader black sand beach backed by a flat at about 5–10 m. and then by the gullied slopes of Ashen Hills. This beach continues the curve of the bay for another 2·5 km. until its termination against the vertical sea cliffs of lava that run out to Nattriss Point, the eastern extremity of the island. This headland is a jagged claw of lava, divided at its end into three rocky projections; it is flat-topped near its extremity but farther inland it is surmounted by a long narrow ridge extending along the promontory to join Ashen Hills. North of the coast about 600 m. west-north-west of Nattriss Point and 300 m. offshore is an isolated reef, mostly awash in a heavy sea.

At Nattriss Point the coast turns and runs south-westward, in a series of small lava headlands and bays, all of them walled by vertical cliffs about 30 m. high. Where the Nattriss Point promontory abuts on Ashen Hills, these lower lava cliffs become merged in and surmounted by high banded cliffs of debris. About 2 km. from the point, these cliffs bisect a minor explosion crater, which makes a striking landmark when the island is approached from the south. This crater is about 800 m. in diameter and its rim is about 180 m. above the sea; like the other craters of the Ashen Hills group, its inner surface is gullied by converging erosion channels. Beyond it, passing westward, the coast begins to turn in a slow curve northward and it is composed of a series of low headlands and small shallow bays below the gullied flanks of the western mass of Ashen Hills. Beyond the col by which these are linked to the main mass of Mount Michael, the slopes and coast of ash and sand are replaced by a crevassed, gently inclined glacier and low ice cliffs. This ice coast runs in a westward and then north-westward direction in a series of bays and prominences not well mapped or photographed, and, curving about the western base of Mount Michael, it turns north-west to Carey Point and Ollivant Point at the western extremity of the island. This coast is for the most part ice cliff up to 75 m. in height but rock cliffs are evident at several headlands and conspicuous at Carey Point and Ollivant Point. The mapping and description of this coast needs further attention, however, since it has not been recorded either in radar-screen photographs or other photographs and it is one of the least known in the island group. For this reason it is by no means certain that Carey Point, as indicated on the present maps, has been identified with the feature for which this name was originally proposed.

North of Ollivant Point, the ice cliffs and slopes extend for a little over 1 km. before giving way to the even lava cliffs surrounding the northern platform and running out to Harper Point. These cliffs, like those on the north-east coast, are for the most part sheer and lack deep indentations.

Topographically, Saunders Island has three main areas: the northern lava plain, the central ice-covered cone and the south-eastern peninsula. The northern plain, Blackstone Plain, has an undulating surface between 30 and 50 m. above sea-level, for the most part made up of very rugged basaltic lava. The whole rocky desert lacks landmarks and is monotonous in its large-scale features, and this, coupled with its irregularity in detail and roughness of surface, makes it tedious and confusing to traverse. The lava is


N
NATTRISS POINT
BROTHERS ROCKS
CORDELIA BAY
ASHEN HILLS
SOMBRE POINT
YELLOWSTONE CRAGS
BLACKSTONE PLAIN
HARPER POINT
MOUNT MICHAEL
OLD CRATER
CRATER
57°45′ S.
OLLIVANT POINT
CAREY POINT
0
1000
2000

patchily overlain by basaltic cinders and ash, the thickness of which appears to increase towards the southern end of the plains in the vicinity of Sombre Point. In a very few localities, mostly at the base of low lava cliffs, there are green moss patches on Blackstone Plain which may owe their origin to mild local fumarolic activity.

Along its southern margin, Blackstone Plain abuts on gentle slopes of crevassed glacier descending from Mount Michael. In its south-eastern corner, 1 km. from Sombre Point and near to the junction with the ice field, the surface of the plain is diversified by two large and several minor upstanding masses of eroded yellow tuff, Yellowstone Crags, which reach a maximum of about 55 m. above the level of the lava platform. The eastern of the two larger hills measures about 200 m. east–west by 90 m. north–south and from its north-western corner a line of pinnacles runs for about 75 m. in a northerly direction. It is separated by a gap of about 185 m. from the western hill which extends for approximately 275 m. and is elongated in a north-easterly direction; from the south-east corner of this hill a crescentic ridge only 10 m. high trends northward parallel with its eastern edge. The western hill reaches a height of about 85 m. above sea-level, whereas the eastern hill is only 8 m. or so lower. Both hills have an elongate summit ridge and, in the case of the western hill, this gives way below on all but the southern side to nearly vertical cliffs 25 m. high in places with long scree slopes reaching down from the base of the cliffs to the encircling lava. The eastern hill is formed almost entirely of loose scree but steep cliffs appear in a few places, notably at the south-eastern corner and around the pinnacles on the north-west side. Yellowstone Crags are conspicuous landmarks from both land and sea on account of their form and colour; partly for this reason, the westernmost was used as a main survey station in 1964. It seems likely that Yellowstone Crags were the "two hills seen over the northern point, which might be two islands" recorded by Cook at his discovery of the island. A hill in the same position was drawn by Bellingshausen's artist, Mikhaylov, in 1819.

The central mass of Saunders Island is the single ice-covered cone of Mount Michael, rising to nearly 1,000 m. above sea-level. This cone is the most shapely and simple mountain in the South Sandwich Islands and it rises in gradients which steepen progressively with altitude. All about the base the glaciers fall at a low angle; their surfaces are heavily crevassed and covered in layers of scoria which in March 1962 and 1964 were conspicuous, no doubt in part because of summer ablation. Higher up, the surface of the cone steepens and is covered by blocky ice which is rendered particularly curious in appearance by the rounded excrescences of rime coating its surface. This rime is undoubtedly deposited in large quantities by condensation of the steam emitted so copiously from the active crater. In 1962 and 1964, the upper slopes of this cone seemed remarkably uniform and no minor vents were observed; the "deep rift or gully partially free from snow, extending up the mountain" on the northern side, recorded by Kemp and Nelson (1931), was not seen in 1962 or 1964, although on the former occasion the peak was seen from Yellowstone Crags against a clear sky. From oblique air photographs taken in 1964, there is, however, a suggestion of a fairly deep snow-covered gully on the north side of the cone, which is possibly equivalent to that seen by Kemp and Nelson.

Photographs of the crater of Mount Michael, taken from a helicopter at summit level in 1964, indicate that the present vent with its low surrounding rim lies partly within an outer crater whose rim is conspicuous on the south. Between the two crater rims on the south of the present vent there are patches of snow-free ground from which steam rises. In a photograph taken in 1956 these are also visible, and around the edge of the main vent are conspicuous cauliflower-shaped masses of rime which may well be built up over fumaroles as are formations of the same aspect on Mount Erebus.

The south-eastern peninsula of Saunders Island is again quite unlike the northern and central areas. For the most part, it is occupied by a mass of rounded whale-backed uplands composed of loosely consolidated ash and lapilli, and channelled by numerous small V-section erosion gullies. These uplands, which are largely free from ice and snow, are named Ashen Hills and appear to have been built around four craters. Of these, the largest lies at the west, where the hills join the ice slopes falling from Mount Michael. It is about 1 km. in diameter and 150 m. deep, and from it a melt-water stream, passing north-eastward through a breach in the rim, drains into Cordelia Bay. On the southern side, the rim of the crater rises to a broad, barren wind-swept col between Ashen Hills and Mount Michael. The second largest crater is that sectioned by the southern coast west of Nattriss Point and this has already been described. The third lies beside and just east of the largest in the group and is about 400 m. in diameter; it is breached on the east so that it forms an embayment in the face of the hills above Cordelia Bay. From it, drainage channels run to the shore. Finally, the fourth and least distinct of the craters forms little more than a vague recess where the Nattriss Point ridge meets Ashen Hills.

The ridge from Ashen Hills to Nattriss Point is, in its landward beginning, a steep-sided flat-topped projection about 100 m. above the sea. As it continues, however, it narrows to a crest perhaps 20 m. across. Near the end of this upper ridge, where a suitable helicopter landing place was found with a southerly wind, a main survey station was established in 1964 linking north to Yellowstone Crags and south to Montagu Island. East of this point, the ridge drops at a moderate angle for about 20 m. and runs on to a rocky crest formed of coarse yellow tuff superficially identical with that forming Yellowstone Crags and weathering into similar rough masses. Beyond this crest the ground drops steeply to the lava platform of Nattriss Point, the only conspicuous mark on the smooth slopes of banded ash being a large round hole which, from the sounds heard nearby, appears to communicate with a sea cave running in from the V-shaped bay near the apex of Nattriss Point.

Offshore from Saunders Island, especially in Cordelia Bay, there are numerous rocks of which the most conspicuous are Brothers Rocks, two pointed masses about 1·9 km. east from Sombre Point. Other reefs lie south from these, partly obstructing Cordelia Bay, but the southern half of the bay is clear and has been used as an anchorage by small vessels.

The first recorded landing on Saunders Island was by C. A. Larsen in 1908, probably in Cordelia Bay. In 1937, a party from *William Scoresby* went ashore in this area. The beach of black sand in the southern part of the bay under Ashen Hills is a good potential landing ground provided the swell is not heavy. In 1961, a party landed by boat from *Shackleton* on the south coast of the island, but in a narrow lane of open water between a belt of pack ice and the shore. In 1962, a helicopter landing was made from *Protector* near Yellowstone Crags, and in 1964 landings were made here, on Blackstone Plain near Harper Point, on the col between Ashen Hills and Mount Michael, and on the ridge above Nattriss Point. The latter place proved hazardous to approach with a south-west wind because of severe turbulence.

Saunders Island was the subject of a sketch survey made by C. A. Larsen in 1908, but this was in general less accurate than the small outline given by Bellingshausen 100 years earlier. In 1930, *Discovery II* made a running survey which is still the only available source of information about the coast between Ollivant Point and the south-western angle of the island. In 1962, a helicopter from *Protector* obtained a series of vertical air photographs of the shore of Cordelia Bay from Nattriss Point almost to Harper Point and re-determined the height of Mount Michael by altimeter as 990 m. In 1964, some oblique air photographs and radar-screen photographs of most shores were taken, a distance measured from Nattriss Point to Yellowstone Crags along a line whose bearing was also determined, and sun observations for position and azimuth were obtained. The present map has been compiled from all available sources but it is dubious for the central western coast.

2. *Geology*

It is suggested that the following sequence of events has occurred on Saunders Island:

5. Eruptions of basaltic cinders from the summit crater of Mount Michael.
4. Emission of the olivine-basalt of Blackstone Plain from Mount Michael.
3. Development of the pyroclastic cones and associated lava flows to form the south-east peninsula.
2. Earlier lavas and pyroclastics of Mount Michael.
1. Tuffs, agglomerates, etc. of Yellowstone Crags, Brothers Rocks and associated centres.

a. *Yellowstone Crags area.* Brothers Rocks, together with various other stacks and reefs, rise from a zone of shallow water occupying the northern part of Cordelia Bay. Earlier volcanic centres were probably situated within this area. Yellowstone Crags which protrude through Blackstone Plain are believed to be of a similar age and possibly of similar rock type to Brothers Rocks. These hills are conspicuous topographic features which have no obvious counterpart on the remainder of Saunders Island. They are clearly older than the basalt of Blackstone Plain which has flooded around them. Where their slopes are not formed by scree, they are bounded by vertical cliffs up to 25 m. high. It is most likely that such cliffs have been cut by marine erosion; the hills were perhaps once offshore stacks or islets similar to Brothers Rocks, which became part of the main island only when partially engulfed by a flood of recent basalt from Mount Michael. Although there are local dips of up to 10°, the tuffs and agglomerates forming Yellowstone

Crags are for the most part horizontal. This would suggest that they have not formed about a local secondary centre in the immediate vicinity but have been derived from a relatively distant source.

Both hills are formed of two main units, which are best seen at the south-eastern corner of the eastern hill:

	m.
Yellow tuff and agglomerate	15
Cinder tuff	4·5

A similar succession is also seen in the tall pinnacles at the north-western side of the same hill but yellow tuff and agglomerate form all exposed parts of the western hill with the exception of the low ridge, lying between the two hills, which is composed of cinder tuff.

The yellow tuff and agglomerate consist of assorted lava blocks and fragments, including cinders set in a yellowish matrix. The cinder tuff is less consolidated and is composed of loosely compacted coarse black and red cinders with relatively little matrix. Pale brown glass and patches of yellow palagonite are important constituents of both the yellow tuff and the cinder tuff. The scree is formed of the disintegrated tuff and agglomerate, and it contains large lava blocks of various types. On the southern side of the two hills, recent basaltic cinders from Mount Michael are patchily distributed across the scree.

There is evidence that the cinder tuff forming the lower part of Yellowstone Crags (Fig. 11) is underlain by an older basalt which is aphyric and quite distinct from the porphyritic basalt of Blackstone Plain. This dark grey aphyric basalt crops out at two localities. It appears as a jagged 1 m. high projection at the western foot of the cinder tuff which crops out along the low narrow ridge between the two main hills. A similar aphyric basalt protrudes through the scree slopes near the foot of the northern slopes of the eastern hill.

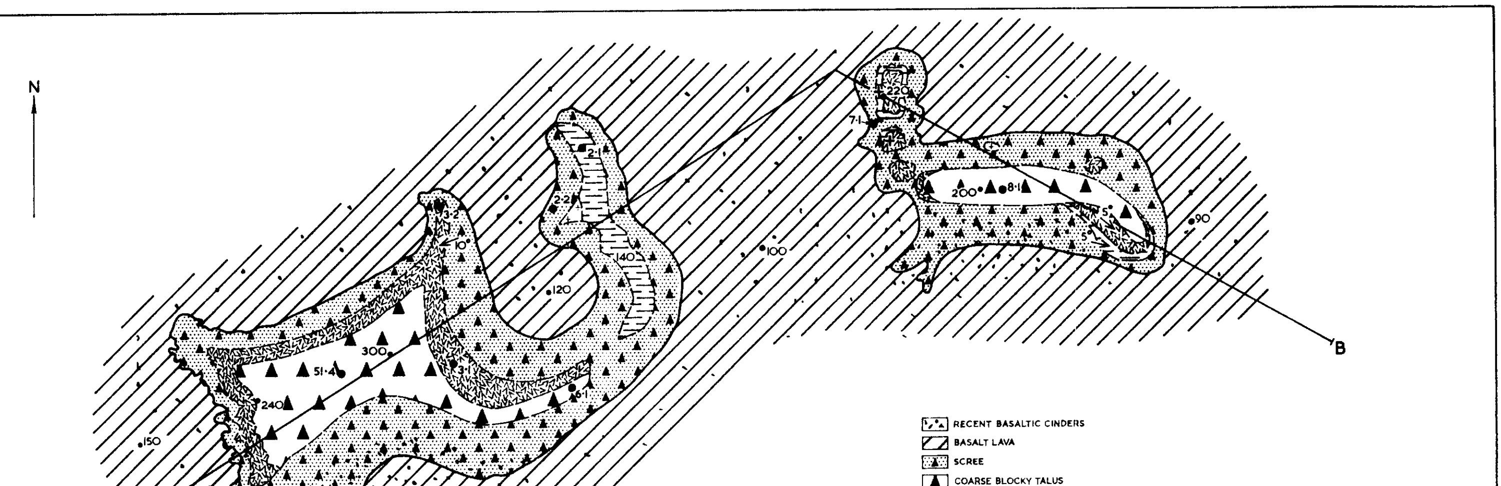


FIGURE 11

Geological sketch map of the Yellowstone Crags area of Saunders Island. The cross-section A–B illustrates the volcanic evolution of this part of the island. The legend applies both to the geological map and the cross-section.

b. *Nattriss Point area.* The following general succession is exposed in the vicinity of Nattriss Point:

	m.
Yellowish tuff, ash and agglomerate	4·6
Dark lapilli and ash	0·5
Basaltic cinders and ash	0·3
Basaltic lava	30

The yellowish tuff and agglomerate at the top of the succession is less consolidated and contains a higher proportion of basaltic constituents than that at Yellowstone Crags. It seems likely that almost all of the material exposed in the Nattriss Point area has been derived from the nearby cones. The pale grey aphyric basalt lava forming the basement for some of the pyroclastics was probably emitted from one of the cones before being partially covered by further pyroclastic falls. The series of parasitic cones which form Ashen Hills are composed largely of a brownish vitric ash containing assorted lapilli and blocks. The entire south-eastern peninsula is probably a relatively recent addition to Saunders Island.

c. *Blackstone Plain.* Blackstone Plain is apparently constructed of several closely related flows of similar composition which were probably emitted in a single episode of activity. The surface of the lava field is composed of aa, pahoehoe and blocky phases, although vesicular spikey aa is the commonest. This rubbly surface grades down into a massive and compact dark grey basalt which is well exposed in the sea cliffs. The basalt is strongly porphyritic, the plagioclase, clinopyroxene and olivine phenocrysts being readily distinguished in the hand specimen. There is evidence that this lava field is of a very recent origin. For instance, apart from the light sprinkling of cinders, the surface of the flow appears to be very largely in its original condition, quite delicate structures being well preserved. There is no ice cover on Blackstone Plain but given sufficient time, the glaciers from Mount Michael might be expected to extend across the area.

From Kemp and Nelson's (1931, p. 172) account, it is clear that Blackstone Plain was in existence in 1930, and from Mikhaylov's sketch of 1820 (*in* Kemp and Nelson, 1931, p. 174) it was apparently present at this date also. It is not, however, clear from Cook's (1777) account whether the plain had formed at that time. Although the precise age of the Blackstone Plain lava field is uncertain, it can with good reason be regarded as only a few hundred years old. In view of this, it is interesting that Kemp and Nelson (1931, p. 173) mentioned that, on the northern side of the cone of Mount Michael, "a deep rift or gully, partially free from snow, extends up the mountain, calling to mind the curious fissures seen in the cone of Zavodovski".

The basaltic cinders scattered across the surface of the lava on Blackstone Plain and on the slopes of Yellowstone Crags are almost certainly equivalent to those sprinkled across the glacier in other parts of the island. The cinders are dark brown to black, sometimes with a bluish lustre; they are partly glassy but also contain phenocrysts of plagioclase, olivine and pyroxene. They undoubtedly represent the most recent activity from Mount Michael and some at least may be only a few years old.

In 1820, Bellingshausen recorded that Saunders Island was "emitting dense vapour from its ice-covered summit". Activity was not noted by Larsen in 1908 but it was seen in 1927, 1930, 1937, 1952, 1956, 1958, 1961 and 1962. In all these years it took the form of emission of a large plume of vapour from the main summit crater. Voluminous clouds of vapour were billowing from the crater and drifting down the eastern slopes of the cone during the short time that it was under observation during the 1964 survey (13 and 14 March). A sulphurous smell, presumably associated with this vapour, could be detected in the vicinity of Yellowstone Crags. There is no historic record of activity in any other place but Kemp and Nelson (1931) drew attention to the striking discrepancy between Mikhaylov's drawing of the south-eastern area in Bellingshausen's account and the conditions today. Mikhaylov was in general scrupulously accurate in his drawings and, even though Saunders Island was seen in poor conditions with low cloud (which probably accounts for his omission of Mount Michael as a high cone), it is surprising that Mikhaylov should have drawn a prominent, single upstanding ice-free cone in the Ashen Hills area if this was not in fact the case. The possibility exists therefore that some of the eruptions in the Ashen Hills complex have occurred since 1820, leading to the disappearance of the single high cone and its replacement by the more rounded and extensive ridge now to be seen.

3. *Vegetation and fauna*

Saunders Island is relatively barren, perhaps partly because of its porous substratum and lack of surface water. Cook, in 1775, referred to the two hills he saw over the north point as appearing to be covered with green turf; if these were Yellowstone Crags, the greenery was probably *Prasiola crispa* which still covers part of them today and is the most widespread plant on the island, occurring wherever there are penguin colonies. Almost the only other vegetation consists of sparse patches of lichen on rocks around Blackstone Plain and Yellowstone Crags, and a few patches of moss on Blackstone Plain. Soil micro-fauna is, however, more abundant in these areas.

The main penguin colonies on Saunders Island are at Nattriss Point, on the eastern flanks of Ashen Hills and on Blackstone Plain, especially near Yellowstone Crags. In all these areas there are many thousands of birds. There are also small groups (hundreds) elsewhere on Blackstone Plain and on Ollivant Point in the north-west, and perhaps also on the central south coast below the col linking Ashen Hills to Mount Michael. At Nattriss Point and Yellowstone Crags in March 1964, moulting chinstrap penguins (*Pygoscelis antarctica*) were the most abundant species by far, with macaroni penguins (*Eudyptes chrysolophus*) occurring in groups up to 50 or 100 strong and perhaps accounting for 0·05 per cent of the total. Much the same impression was gained on Blackstone Plain in March 1962. Several hundred gentoo penguins (*Pygoscelis papua*), including young birds, occurred with the other species on the lower slopes of Ashen Hills where they have a colony. This record is in accordance with Wilkinson (1956) and Kemp and Nelson (1931), but the latter claimed also to have seen king penguin (*Aptenodytes patagonica*) ashore in Cordelia Bay in 1930; this species was never observed by us in the South Sandwich Islands. It is likely that the Adélie penguin (*Pygoscelis adeliae*) breeds on Saunders Island but recent visits have been too late in the season for this to be confirmed.

About Cordelia Bay, the other birds seen on land were a few gulls (*Larus dominicanus*), giant petrels (*Macronectes giganteus*), many Wilson's petrels (*Oceanites oceanicus*), one tern (*Sterna vittata*) and some cape pigeons (*Daption capensis*). Of these, the gulls, Wilson's petrels and terns may breed in the area but the others probably do not occupy this part of the island. At Yellowstone Crags, a single tern seen was chattering noisily and could have been defending territory, but it was only seen on one occasion and did not re-appear. There was no sign of a nest but the terrain was such that this could easily have been overlooked. A single shoemaker (*Procellaria aequinoctialis*) was seen to fly over this area but it is not thought that the species breeds here. Skuas were present both on land and flying over the island, and a chick of this species was seen in the area in 1962. Giant petrels were also observed in flight and on the ground but there is no indication of their breeding.

Fur seal (*Arctocephalus tropicalis gazella*) were observed on Saunders Island at several points but no confirmed breeding groups were seen. On the black sand beach in Cordelia Bay, north of Nattriss Point, four male fur seals were seen on two occasions. To the north of Yellowstone Crags, near Harper Point, there was a group of 43 fur seal consisting of adult males and a number of juvenile animals of both sexes, of which 13 were identified as female; no pups were seen at all. A similar group of 30–50 was found here and reported as breeding in 1962, but it seems likely that yearling animals were mistakenly identified as moulted pups on this occasion.

A further group of 30–40 fur seal were seen from the helicopter during a flight around the island, just south of Sombre Point. Unfortunately, it was not possible to investigate more closely but it is thought that this was probably another non-breeding group. Moulting elephant seals were found to be very abundant on the black sand beach north of Nattriss Point. On 14 March 1964, 229 were counted and on 16 March only 166 animals were seen. On the earlier date, six Weddell seals were also observed but these had gone by 16 March. Leopard seals were common in the sea at both Nattriss Point and in the Yellowstone Crags area, and four were seen ashore on the black sand beach on 16 March. It seems likely that elephant seal may breed on this island and that fur seal colonies may be established in the future.

G. Montagu Island

1. *Topography*

Although it is the largest and highest in the South Sandwich Islands group, Montagu Island (Fig. 12) has been rather imperfectly studied and mapped, due particularly to the difficulties of access to and travel

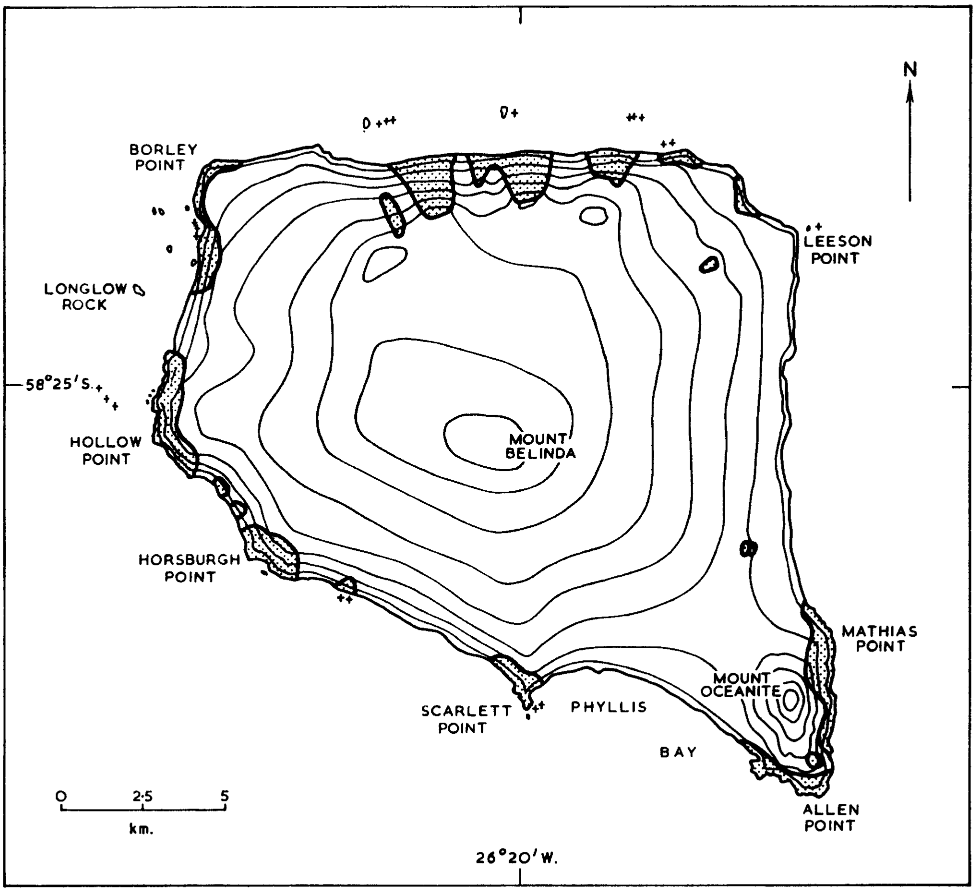


FIGURE 12
Sketch map of Montagu Island.

over its precipitous coasts and ice-capped terrain. In broad outline, the island is an irregular quadrilateral, with approximately rectangular corners in the north-west and north-east and a tapering, acute-angled projection in the south-east. The maximum north–south length of the island, along the east coast, is 19 km., while the breadth from west to east is almost 20 km.; in the centre of the island a high ice-capped plateau is overtopped by the cone of Mount Belinda, which is approximately 1,370 m. high.

The north coast of Montagu Island, aligned almost due east–west so that there is no distinct northernmost point, is for the most part formed by towering rock cliffs alternating with ice falls. Above Borley Point in the north-west, the cliffs are rather low and regular, composed of black lava; at about 50 m. the cliff top forms a narrow shelf below the front of a small ice piedmont. This piedmont, which extends to the sea in ice cliffs east of the point, slants inwards to a minor cone-shaped peak in the north-west corner of the summit plateau. From here a cliff line of rock, partly overlain with steep ice slopes, swings out to the north coast and forms its central section. Viewed from the north, there are four major rock buttresses in this area, the easternmost capped by ice, and three of them rise to subsidiary peaks on the lip of the main plateau. Two of these peaks are abrupt rock horns when seen in profile from the east, contrasting dramatically with the even snow slopes to landward of them.

East of this precipitous section of the north coast, the height of the land falls steadily and in the north-eastern corner of the island a low lava outcrop flanking a small embayment is overtopped by ice to make a cliff line whose total height is little more than 50 m. The whole east coast of the island, trending from Leeson Point almost due south for 15 km. is formed by uniform ice cliffs with virtually no exposed rock on average only about 30 m. high and terminating the gradual slopes of the eastern ice field of the island. Only when the south-east headland of Allen Point is reached is there a sudden contrast, steepening ice slopes giving way to inclined rock and ice falls slanting at an overall angle of about 40° all the way from the

900 m. summit of Mount Oceanite to the sea. About the base of the peninsula there are several minor juts of rock; one of these (Mathias Point), in the north-east corner below a pinnacled buttress which divides the rocky flanks of the cone from the ice cap to the north of it, was the site of a survey station in 1964.

The south and south-west sides of the Allen Point promontory are surrounded by low lava cliffs about 50–75 m. high with some areas of reef and rock shelf to seaward of them. Passing westward, the long regular curve of Phyllis Bay is backed by an ice cliff with a narrow beach of black sand flanking the ice in places. Towards the western end of the bay the slopes above the coast steepen and rock re-appears at the narrow projection of Scarlett Point. From this point westabout to Borley Point in the north-west of the island, the coasts are composed of alternating ice falls and rock cliffs which on the west coast, especially around Hollow Point, are as high and sheer as on the central northern coast. Beaches are few and narrow all round this coast, but they are developed in places between Horsburgh Point and Scarlett Point where they consist of black sand and boulders backed by ice cliff.

There are a number of off-lying rocks about Montagu Island. Off the north coast there are two stacks each about 15 m. high with many attendant rocks, while off the west coast Longlow Rock is a long serrated ridge about 30 m. at its highest point. Several other stacks off this west coast approach 15–20 m. in height and, as on the north, there are many smaller rocks and blinders. In contrast, the east side of the island is relatively free from danger.

Topographically, Montagu Island consists of two major units. The greater part of the island is occupied by the flanks and crest of a high plateau which mounts in even and unbroken ice slopes from the east and south coasts and from the crests of the high western and northern cliffs. Along the west and north coasts, the edge of the plateau and the tops of coastal rock buttresses are locally marked by subsidiary summits but these rise to no great height above the adjacent levels. Near its margin, the ice plateau is pierced by at least three apparently quite recent parasitic cones. Two of the cones project through the glacier about 1·6 km. inland from Leeson Point, the north-eastern point of the island, and are probably built of scoria and cinders. The larger of the two is apparently breached and has emitted a lava flow towards the north-east. The smaller cone lies about 230 m. inland from the larger one. Another small cone protruding through the glacier about 1·2 km. inland from Leeson Point is a lower and broader feature which has every appearance of being older than the northern ones.

This central plateau itself, seen from east or north, has a uniform crest at perhaps 1,000 m., though no doubt on closer inspection, it would prove to undulate to some degree. On its southern side, the rounded mass of Mount Belinda rises a further 300 m. In contrast to this broad, rather gently sloping central upland, the second topographical division of the island, the south-eastern headland, is surmounted by the symmetrical and steep-sided Mount Oceanite. This peak, about 900 m. high, has a domed summit mantled by ice and crevassed sheets of ice overlie its upper slopes giving way to rock locally lower down. On the landward side, the peak is joined to the main upland only by a low ice col, perhaps 180 m. above the sea; on the seaward side at the south, the flanks of the mountain run with steadily decreasing angle into a terrace of rock and snow above the coastal cliffs.

Montagu Island is one of the most heavily ice-covered of the South Sandwich Islands group, the whole interior being buried beneath a single ice cap which is only locally divided into glaciers where it spills over the higher and more rocky coasts. The subsidiary volcanic peak of Mount Oceanite is also well covered in ice and snow, and it is only on the southern flanks of the latter, above Allen Point, that there is any nearly level lowland showing exposures of rock and debris.

Biscoe may have landed on Montagu Island, probably near Allen Point, when searching for fur seal in 1830. Larsen put a party ashore here in 1908, and on 20 January 1957 a group from *Slava 15* contrived to beach a boat on a sandy and rocky shore somewhere on the south coast. In 1964, helicopter landings were made on several occasions on the terraced lowland south of Mount Oceanite, on the rocky rib of Mathias Point north from Allen Point and at a point on the north-eastern ice slopes. Turbulence, which is pronounced in the lee of the island with a wind of any strength, hampered helicopter operations.

A rough sketch map of Montagu Island was made by Larsen in 1908 but the first careful survey was made by *Discovery II* in 1930 (Kemp and Nelson, 1931). The present map, the coastline of which is based on radar-screen photographs obtained in March 1964, tallies well with the *Discovery II* survey. Topographical detail has been sketched from photographs and is not accurately laid down. The height of Mount Belinda was determined as about 1,370 m. by Nelson in 1930 and this figure has been accepted subsequently.

The height of Mount Oceanite, assessed as only 490 m. by Nelson, was found to be about 900 m. by helicopter altimeter and angles from *Protector* in March 1964.

2. *Geology*

Rocks collected from Allen Point during Larsen's visit in 1908 were described by Baeckström (1915) and referred to again by Tyrrell (1945). During the 1964 survey, rock collections were made at Allen Point, Mathias Point and in the vicinity of Horsburgh Point.

The bulk of Montagu Island appears to have been built around the primary volcano, Mount Belinda, although substantial contributions may have been made from other centres which were possibly located to the north of Mount Belinda. In addition, there are the obvious secondary centres of Mount Oceanite and the small parasitic cones situated some way inland from the edge of the cliffs.

The general uniformity of the pyroclastic deposits exposed in coastal sections on the west side of the island suggests that they have probably been derived from the main centre. The following section exposed in the cliffs behind Horsburgh Point beach appears to be fairly characteristic of these deposits; and it is overlain by a considerable thickness of ice.

	m.
Pale grey basalt	15
Red scoria and agglomerate	2·4
Black scoria and cinders	5·5
Re-distributed yellow tuff	4·6
Yellow tuff and agglomerate	18

The lava forming the topmost part of this section appears to extend downward probably filling a valley, to form Horsburgh Point itself. The lava is a pale grey basalt consisting of phenocrysts of plagioclase in a groundmass of plagioclase, clinopyroxene and magnetite. Irregularly staining the surface of the lava is a bright bluish green deposit which on X-ray analysis proved to be the mineral atacamite ($CuCl_2.3Cu(OH)_2$).

The Horsburgh Point beach section is much the same as that seen to the south of Hollow Point and again along parts of the northern coast, but at the north-eastern corner of the island the entire cliff is apparently composed of a pale grey tuff or ash, which possibly originated from a secondary eruptive centre in this area.

Mount Oceanite which dominates the south-eastern part of Montagu Island is clearly a secondary volcanic centre. There is no proof of the existence of a crater at its summit and it is therefore just possible that the feature originated as a volcanic dome tilting up the older lavas and pyroclastics on its flanks. On the other hand, several lines of evidence point to it being a secondary cone, the summit crater of which has been obscured by ice and snow. It has, for instance, a rather symmetrical form with flanks sloping at about 30°, features which are fairly characteristic of volcanic cones. Viewed from a distance, the summit has a flattened profile suggestive of a crater rim. In addition, the pyroclastics dipping seaward off the north-eastern side of the feature appear to be very well and evenly stratified as if they were deposited at no great distance from the vent; they do not show the severe dislocation and steep dips which might have been expected had they been thrust into their present position by a rising dome.

The headland running out to Allen Point is formed by an oceanitic lava flow which is well exposed in the sea cliffs and also forms innumerable blocks littering the relatively ice-free surface. From the disposition of trains of these blocks which converge towards a point low on the south-east side of Mount Oceanite, it may be supposed that the flow was emitted from a boca on this side of the cone. It is clear that this lava flow was discharged after the cessation of explosive activity as there are no pyroclastic deposits resting on it.

The oceanitic lava contains abundant phenocrysts of dark green pyroxene up to about 5 mm. in diameter together with pale yellowish green olivines which are generally somewhat smaller. Apart from occasional very large crystals, the plagioclases tend to be relatively inconspicuous in the hand specimen but they are quite abundant as can be seen in thin section. No other lavas collected from the South Sandwich Islands were as strongly porphyritic in pyroxene and olivine as these specimens from the south-eastern peninsula of Montagu Island.

The lava forming the headland at Mathias Point on the north-eastern side of Mount Oceanite is of a very similar type but it is inclined to be less coarsely porphyritic. It is overlain by about 6 m. of scoriaceous material together with assorted debris which has slipped from the cliffs behind. The whale-backed lobate headland immediately to the north of Mathias Point is built by a well-jointed lava flow but it is not known whether this is also of oceanitic character. Oceanitic dykes form conspicuous walls standing about 15 m. high with ragged crests, cutting through the lower flanks of the cone and running into Mathias Point. The protective influence of these dykes may in fact be partly responsible for the preservation of the two narrow headlands at Mathias Point. Specimens were collected from one of the dykes where it is about 1·2 m. wide on the lower northern side of Mathias Point. Although the groundmass of the margin is distinctly chilled, it retains the large olivine and pyroxene phenocrysts seen elsewhere.

Approximately 2 km. inland from the north-western foot of Mount Oceanite the gently rising glacier ascends a distinct cliff in which there are small rock outcrops. This cliff probably represents an old shoreline which used to trend south-westward from here to Scarlett Point. In the area between the old cliff line and Mount Oceanite there are no rock exposures; the relatively low cliffs are entirely of ice and there are no off-lying rocks as in other parts of the island. It is possible that this broad isthmus linking Mount Oceanite with the main part of Montagu Island is underlain by a lava flow or flows extruded from the south-eastern part of the island prior to the construction of the large secondary cone.

Although geological information about Montagu Island is still very limited, it is possible that the following sequence of events has occurred:

6. Construction of the recent parasitic cones (probably basaltic) situated on the periphery of the plateau.
5. Intrusion of oceanitic dykes at Mathias Point.
4. Extrusion of oceanitic lava flows from Mount Oceanite.
3. Construction of the pyroclastic cone of Mount Oceanite.
2. Eruption of older secondary centres along the northern side of Montagu Island.
1. Lavas and pyroclastics of Mount Belinda.

There are no records of volcanic activity at any time. Kemp and Nelson thought the Allen Point promontory retained some volcanic heat because it was ice-free low down on the south and east but this seems a dubious hypothesis. There was no evidence of warmth on the ice-free areas in March 1964; on the contrary, the ground was hard and frozen. The local absence of ice is probably to be attributed to the influence of Mount Oceanite which shields the Allen Point promontory from the ice cap of the main part of the island. On the north-eastern and south-western sides of Mount Oceanite, where steep slopes descend directly down to the sea, the paucity of ice around the base of the feature may be accounted for by marine erosion, the steep gradient and its effect in inducing avalanches.

3. *Vegetation and fauna*

On the southern flanks of Mount Oceanite above Allen Point, areas of boulder and debris are locally overgrown or encrusted with lichen, and a few mosses have been collected among the rocks and in areas where melt water percolates in summer. Here, around penguin colonies, patches of the green alga *Prasiola crispa* are conspicuous, and this same plant also occurs locally on the rock cliffs of the south coast. It seems likely that vegetation of this general type occurs on outcrops low down around the island, but it is most improbable that it is anywhere more luxuriant than at Allen Point. The plants collected, and the few mites and Collembola extracted from them, are described elsewhere (Tilbrook, 1967*a*, *b*; Longton and Holdgate, 1979).

There are penguin colonies west of Allen Point and at Scarlett Point; Ivanov (1959*a*, *b*) recorded both *Pygoscelis antarctica* and *Pygoscelis adeliae* in the area where the Russian party landed. *Daption capensis*, *Pagadroma nivea* and *Fulmarus glacialoides* were found breeding on the cliffs nearby, and an abundance of the last species on the cliffs around Allen Point was commented on by Wilkinson (1956).

In 1964, Montagu Island was not studied as closely as others of the South Sandwich Islands group and information is rather scanty. Allen Point was visited and here were found large numbers of chinstrap penguins (*Pygoscelis antarctica*) and fulmars (*Fulmarus glacialoides*), the latter being especially abundant on the slopes to the north of Allen Point. The rocky cliffs north from Allen Point, terminating at Mathias Point, abound in fulmar nests and there are also considerable numbers of chinstrap penguins in those places where they can gain access. At Mathias Point itself, there is a small colony of shag (*Phalacrocorax atriceps*) and about 50 birds were seen here. Skuas (*Catharacta skua lonnbergi*) were seen flying over Allen

Point and may possibly breed, but no nests or chicks were recorded. Giant petrels (*Macronectes giganteus*) were also seen flying in the area and a lone Antarctic petrel (*Thalassoica antarctica*).

Chinstrap penguins were found with moulting chicks at Scarlett Point and also at Horsburgh Point, but in both places probably only a few hundred pairs breed. At the latter place, two pairs of macaroni penguins were found with chicks, and fulmars and cape pigeons nested on the rocky ledges.

The remainder of the island was not examined but, due to its steepness, it seems unlikely that there would be much more than a few fulmars on some of the rocky outcrops. Because there are so few beaches, seals are infrequent but Weddell, elephant and crabeater seals have been seen ashore.

H. Bristol Island

1. *Topography*

Bristol Island (Fig. 13), like Montagu Island one of the largest of the South Sandwich Islands group, has also been most imperfectly explored. In outline, it is rhomboidal with the axes running almost due north–south and east–west; the distances in these two directions are approximately 12 km. and 14 km., respectively. Off-lying to the west of the island, along a line south-westward from Turmoil Point, are three prominent rocky islets.

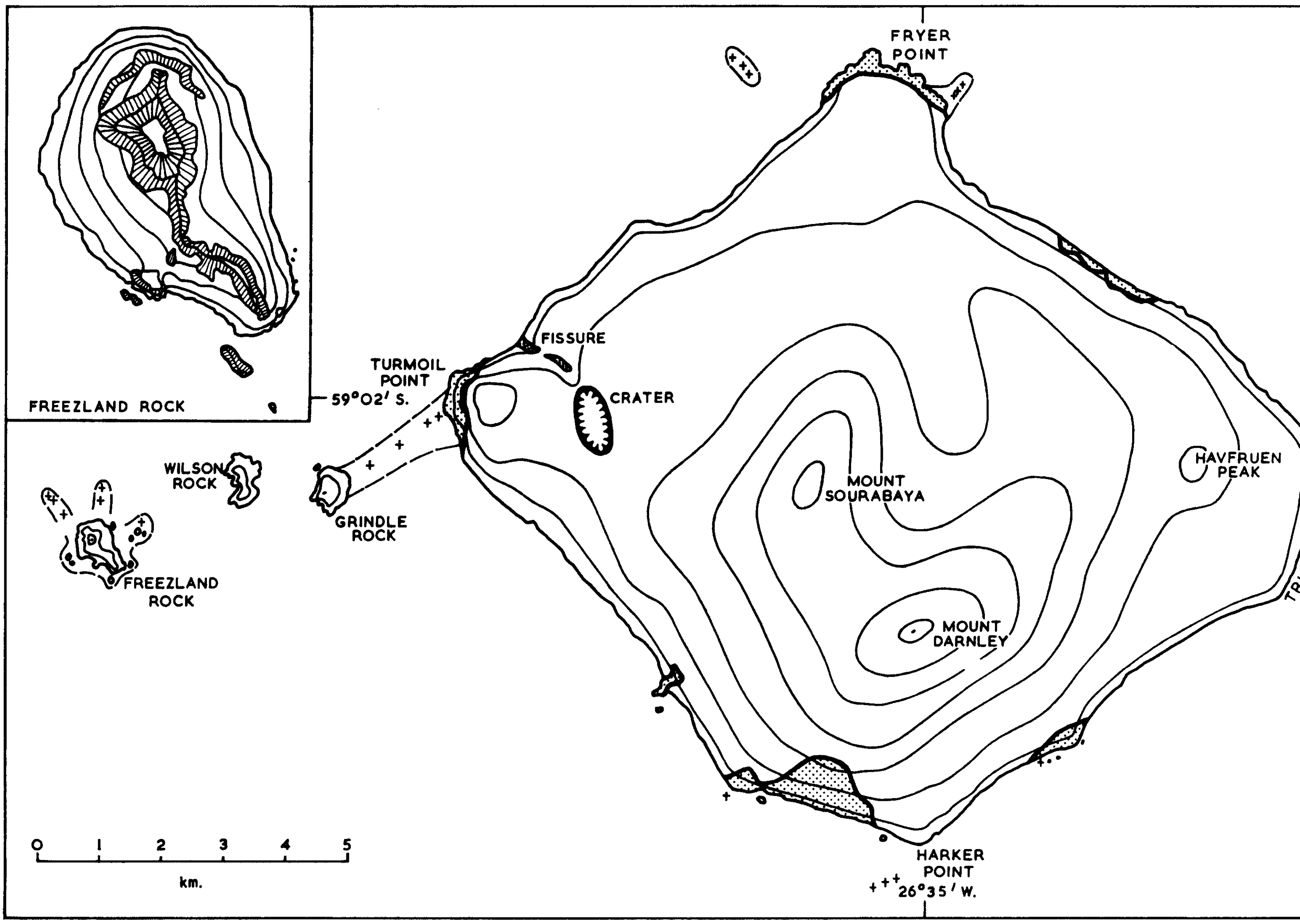


FIGURE 13

Sketch map of Bristol Island.

Fryer Point, in the north of Bristol Island, terminates in an irregular series of lava projections of no great height with reefs and rocks offshore. The inner part of the headland is covered by a glacier and this extends to the coast along most of the north-east coast, terminating in cliffs about 75 m. high. At the east of the island these regular ice cliffs swing in an arc round Trulla Bluff and continue south-westward to Harker Point with but one intervening stretch of low rock cliffs forming a minor headland. Harker Point, the southernmost limit of Bristol Island, is formed of further ice cliffs below high glacier slopes but with rocks awash close offshore, and passing west from it the glacier soon ends as a tumbled ice fall beside a high and rocky bluff. Further ice cliffs, beyond this bluff, continue the coast towards Turmoil Point with the interruption of only one small and narrow projecting lava tongue, about a quarter of the way along the overall length of the south-west coast. Turmoil Point is another high cliffed bluff breaking the continuity of ice cliff about the perimeter of the island, and it is conspicuous in all views from the west, rising about 350 m. from the sea in banded red and grey rocks. Beyond it, the north-west coast, which continues towards Fryer Point, is thrown into a series of slight projections and bays and is again wholly of ice cliff rising above black sand and boulder beaches. Thus, about the island as a whole, ice cliffs account for at least 90 per cent of the coastline and are for the most part regular in height at about 75–100 m. This feature serves to distinguish Bristol Island from all others in the South Sandwich Islands group.

The inland topography of Bristol Island is not well mapped but its salient features are established. Around much of the western, northern and eastern perimeter, even slopes of crevassed glacier mount at a low angle to the foot of a central highland of rounded ice-covered peaks. On the west, above Turmoil Point, there is a subsidiary summit at about 400 m. with a snow-covered rounded crest and this is linked to the main upland by an ice-covered swell trending a little south of east. Just north of the col between the Turmoil Point summit and the main central upland, the even surface of the glacier is broken by a prominent crater, first observed in 1962 from *Protector*'s helicopter. This crater lies between 240 and 300 m. above the sea and is about 220 m. across; in 1962 its depth was estimated at 60 m. and its floor was covered by mounds of dark material which were steaming conspicuously even in poor evening light. A fissure, partly occluded by ice, ran from this crater to the north-west coast in 1962, and the adjacent glacier was covered by black ash. This fissure was still visible though less conspicuous and with less ash around it in 1964.

The central upland of Bristol Island was correctly described by Kemp and Nelson (1931) as horseshoe-shaped. Mount Darnley, the highest peak of the island, reaches about 1,100 m. above sea-level. It is a rather gently rounded ice-covered peak which rises from the central part of the horseshoe above the southern corner of the island. The western peak, Mount Sourabaya, rises more abruptly from the smooth ice fields that ascend from around Turmoil Point; it has steep concave slopes on the west with small rock outcrops near the summit. The third arm of the horseshoe is formed by a spur running north-eastward from Mount Darnley and then curving round to the north and north-west and terminating in a swelling crest attaining about 490 m. not far inland from the north-east coast. East of this curving arm of upland, the final prominent peak on Bristol Island is a detached, very conspicuous horn towering above the uniform ice slopes about 2 km. inland from Trulla Bluff. Its flanks slope for the most part at about 35° but there are nearly vertical cliffs in places; snow and ice cover most of the hill but rock is exposed in several places near the summit. This horn, Havfruen Peak, reaches about 265 m. and has at least a superficial resemblance to Mount Oceanite on Montagu Island, which it faces across the passage to the northward.

South-west from Turmoil Point there are three great rocks which form very distinctive landmarks visible from a great distance. The landmost, Grindle Rock, is a wedge-shaped mass of lava sloping upwards from north and east to a summit 210 m. high above the sheer wall of the western and southern cliffs. Between Grindle Rock and the mainland the passage is strewn with rocks, but deeper water lies to seaward between Grindle Rock and the next rock, Wilson Rock. This is a nearly level-topped mass of lava about 150 m. high, but the base of its sheer cliff wall is surrounded by talus slopes in many places and there are low-lying rock reefs and subsidiary stacks about its perimeter.

Freezland Rock, the westernmost and outermost of the three rock masses, is also the largest, measuring 640 m. by 550 m. It is the highest and most dramatic of the three small islands, its northern summit rising above talus slopes in an obelisk 300 m. high. The central spine of the islet runs south from this obelisk through a slight col to the southern summit, formed of a sheer-sided towering wall of rock about 180 m. high and with a crest only about 2–3 m. wide. Talus slopes flank the base of this wall, as the northern tower, and as at Wilson Rock the perimeter of the islet is marked by several minor stacks and rock masses rising between areas of boulder beach; there are also numerous off-lying rocks.

The first known landing on Bristol Island was by C. A. Larsen in 1908 but the exact place is not known. There is no other record until 1964 when a landing was made from *Protector*'s helicopter on a rocky point on the south-west coast, believed at the time to be Harker Point, but now identified with the smaller rocky projection some way to the west of it. The first and only recorded landings on Freezland Rock were also made by helicopter in 1964, on the boulder beach near the south-west corner of the island. It is likely that boat landings could be made here in very calm weather. Helicopter operations around Bristol Island were made difficult by severe turbulence and it was only with great difficulty that one party was lifted off Freezland Rock following a deterioration in weather.

Bristol Island was surveyed by *Discovery II* in 1930 (Kemp and Nelson, 1931) and this remains the only complete survey of the coast. In 1964, radar-screen photographs were obtained of the north-east, north-west and south-west coasts, and these have been used in compiling the present map; the south-east coast remains based on Kemp and Nelson's work. Inland topography has been sketched from photographs and the coasts of Grindle Rock and Wilson Rock depend largely on the *Discovery II* chart. Vertical air photographs were taken of Freezland Rock and its height checked by altimeter at about 305 m. but no other height determinations have been made in recent visits.

2. *Geology*

The paucity of rock exposures and limited amount of material collected from Bristol Island do not permit a very comprehensive interpretation of the geology. It may reaonably be assumed that most of the main island has been built around the peaks which form the horseshoe: Mount Darnley, Mount Sourabaya and Havfruen Peak. Kemp and Nelson (1931, p. 177) suggested that these peaks may have formed part of the rim of a very large crater. Although their interpretation may be correct, it is also possible that the peaks are separate volcanic centres whose products overlap to a considerable extent. Havfruen Peak is probably a secondary volcanic dome or cone of more recent origin. The lava flow forming the rocky headland west of Harker Point and that forming Fryer Point are almost certainly associated with one or other of these centres. The flow forming the narrow blocky promontory west of Harker Point is overlain by coarse scoriaceous rubble; the lava is a strongly porphyritic basalt, rather pale in colour and with phenocrysts of plagioclase and olivine, the former being particularly abundant. Kemp and Nelson (1931) reported that Fryer Point is formed of a black basaltic lava but this was not examined in 1964. Probably the best exposure on Bristol Island forms the great bluff at Turmoil Point. It consists of interbedded red and yellow tuffs probably with occasional lava flows. The beds have an easterly dip, suggesting that they originated from a source which lay to the west of Bristol Island.

Kemp and Nelson (1931, p. 177) attached great importance to the three islets which lie to the west of Bristol Island, stating that "From a geological point of view the three large outlying rocks appear to be more interesting than any other place in the entire group of islands." Although their observations were made only from a distance, they believed that Freezland Rock was built of sedimentary and metamorphic rocks, Wilson Rock of basalt and Grindle Rock of tuffs similar to those which appear in the nearby coast of Bristol Island. They concluded that the whole succession of rock formations in the South Sandwich Islands is to be found in these three islets. They were almost certainly correct in stating that Grindle Rock is composed of tuffs and Wilson Rock of basalt, although confirmation of this remains to be obtained. They were mistaken, however, in suggesting that Freezland Rock is composed of sedimentary and metamorphic rocks. The bedded deposits forming the highest part of the islet are in fact stratified pyroclastics and the lower eastern peak, which they observed to be composed of a brownish rock with vertical striations and fissures, is in fact formed by andesitic dykes and not by metamorphic rocks.

The higher peak is composed of stratified yellowish tuffs and agglomerates dipping south-eastward at about 30°, capped by about 12 m. of red agglomerate which also appears at the foot of the cliffs in the south-eastern part of the islet. The lower eastern peak is formed by a swarm of andesite dykes which diverge somewhat in a north-westerly direction fanning out in the vicinity of the main peak. One dyke forms a protective wall running along the northern side of the east peak and another rises intermittently along its southern side. A third dyke cuts through the centre of the east peak and continues along the axis of the island probably through the west peak. Three rocks off the southern coast of Freezland Rock evidently constitute the remnants of another dyke and some of the linear reefs may also belong to the dyke system. The fact that the pyroclastic beds of Freezland Rock dip towards the south-east would suggest that they were originally erupted from a centre which lay to the north-west of the present islet. The coarse character of these pyroclastics further suggests that the source vent was at no great distance from the present position of Freezland Rock.

Kemp and Nelson concluded their discussion with the following statement:

"Thus, if our conjectures are correct, the whole succession of rock formations in the Sandwich group is to be found in these three islets. Freezland shows the only likely exposure of the underlying sedimentary series that we know to exist, Wilson is of the overlying basalt, here seen in far greater thickness than elsewhere, while Grindle is formed of the superposed tuffs which are characteristic of all the islands of the group."

Disregarding the incorrect reference to sedimentary rocks, this statement also implies that there is a general sequence throughout the South Sandwich Islands consisting of basalt overlain by tuffs. There is, however, no evidence that a general relationship of this sort exists. On the contrary, it is quite clear that basaltic and andesitic lava flows are interspersed with pyroclastic rocks at various levels. It is true that lava flows tend to form the lower part of the cliffs around most of the islands, perhaps giving the impression that they form a basement for the overlying deposits. In many cases, however, e.g. Blackstone Plain (Saunders Island), the eastern plains of Zavodovski Island, northern Candlemas Island, and the Hewison Point plateau (Thule Island), the lavas do not form a basement but are in fact amongst the most recent products of the volcanoes. This is, therefore, a reflection of the tendency for fluid lavas, emitted at any stage in the development of a volcano, to flow off the steeper slopes and spread about the foot of the cone. Furthermore, where pyroclastic beds are exposed to wave attack, the cliffs will recede relatively rapidly until a more resistant lava is reached and the rate of erosion correspondingly reduced. On Vindication Island, which has been severely eroded, lavas form the base of the cliffs, probably for this reason, but they are by no means confined to this level and occur in several places within the overlying sequence. The frequent occurence of lava flows at sea-level around the South Sandwich Islands may, therefore, be ascribed to erosional factors. The islands are the products of several individual volcanoes which have had quite separate histories; although there are close structural and compositional resemblances between these volcanoes, there is no evidence of a uniform sequence of activity.

It would appear that Kemp and Nelson attached unwarranted significance to Bristol Island's off-lying islets. Together with the great bluff at Turmoil Point on the main island, they indicated that one or more volcanic centres formerly existed off the west coast of Bristol Island. From the attitude of the coarse pyroclastics on Freezland Rock, it is supposed that one such centre was located to the north-east of this islet. The advanced state of denudation of the islets, considered in conjunction with the distance which they extend from the coast of Bristol Island, would suggest that they are relatively old features and are perhaps amongst the oldest rocks exposed above sea-level in the South Sandwich Islands. With this possibility in mind, a K-Ar determination was made on a specimen of one of the dykes from Freezland Rock. The results suggest an age of approximately 4·7 m. yr. (by courtesy of D. C. Rex at the Department of Geology and Mineralogy, University of Oxford).

In conclusion, it would seem that Freezland Rock, Wilson Rock and Grindle Rock, together with the great bluff at Turmoil Point, are the remains of one or more volcanic centres which may have preceded all or part of the remainder of Bristol Island. The bulk of the island appears to have been constructed about the central complex of Mount Darnley, Harker Point and Havfruen Peak. The lava flow at Fryer Point may well have issued from this central area in one of the most recent phases of activity. Havfruen Peak, near Trulla Bluff, is probably a young parasitic centre and most recent of all is the small crater high on the western ice slopes.

No eruption of Bristol Island had been recorded prior to 1930, and Kemp and Nelson in that year concluded from the uniform ice cover and lack of vapour emission that all activity had ceased. However, an eruption of a central peak, supposedly Mount Darnley, was seen on 31 December 1935 from the whaling ship *Sourabaya* (Admiralty, 1948), and on 11 January 1956 men at the Argentine refuge hut on Thule Island witnessed a violent eruption in which three "jets" of glowing material were thrown up an estimated 200–300 m. (Secretaria de Marina, 1958). The eruption lasted 48 hr. and the island was again quiescent when visited by *Protector* in March 1956; no new eruptions have been seen since. It is suggested, but is pure conjecture, that the crater observed in 1962 inland from Turmoil Point was the site of the 1956 eruption. The ice is patchily covered by black cinders or ash in several places near the edge of the cliffs along the west coast. A dense carpet of black ash also rests on the heavily crevassed ice on the eastern side of the island between Havfruen Peak and the coast. The ash is particularly conspicuous in this latter area, perhaps due to the sheltering influence of Havfruen Peak which may restrict the accumulation of ice and snow in this area. Since there is no mention of the presence of ash on top of the glacier in any report prior to that of Holdgate (1963), it is possible that it was emitted in the 1956 eruption.

3. *Vegetation and fauna*

No plant collections have been made on Bristol Island except for a few samples of encrusting lichen and *Prasiola* obtained west of Harker Point in March 1964. On Freezland Rock, however, a more careful search resulted in the discovery of a very few moss patches in a sheltered and stabilized place about a rock outcrop on the western slopes, and of a fair growth of lichen on the southern cliffs. *Prasiola* was conspicuous, as is usual, in the many areas affected by penguins on this islet. This plant may also compose the small patches of "bright green vegetation" observed on Grindle Rock by Kemp and Nelson (1931).

There are few penguin colonies about Bristol Island, Kemp and Nelson having recorded one only, at the small rock headland near Harker Point on the south-west coast. This colony, which in March 1964 contained only moulting chinstrap penguins, was visited by P. E. Baker. The latter found a breeding colony of about 100 shag (*Phalacrocorax atriceps*) in the same area, and this species was also noted in the area from *Discovery II* in 1930 (Kemp and Nelson, 1931).

On Freezland Rock there were abundant penguins on the talus slopes on both west and east coasts, in 1930 and in March 1964. *Pygoscelis antarctica* predominated on the latter occasion and many chicks were among the moulting population. A few *Eudyptes chrysolophus* were also conspicuous. Fulmars (*Fulmarus glacialoides*) were present in great abundance on the narrow southern peak of the island and probably breed there, and skuas (*Catharacta skua lonnbergi*) were seen over the land and had certainly taken some fulmars whose remains were found.

A similar avifauna probably inhabits Wilson Rock and Grindle Rock; many moulting chinstrap penguins were present on both east and west sides of the former in March 1964. The only other species seen near the islands was the shoemaker (*Procellaria aequinoctialis*) which is thought most unlikely to breed here.

In 1962, Holdgate observed fewer than ten fur seal on the north-west coast of Bristol Island. Three of this species were seen at Freezland Rock and about 16 near Harker Point in March 1964, both groups being of non-breeding animals. A few young elephant seal were found hauled out on Freezland Rock.

I. Bellingshausen Island

1. *Topography*

Bellingshausen Island (Fig. 14) is the smallest and easternmost of the three islands forming the Southern Thule group, and it also lies northward of the other two. It is broadly triangular in form if the narrow headland of Jagged Point which projects from the eastern side is excluded from consideration, the apex being at the north. The overall length of the island from north to south is 1·7 km., while the greatest breadth from east to west near the southern coast, is 1·2 km. The highest summit attains 253 m. above sea-level. Salamander Point, the northern extremity of the island, is formed by a narrow fringing lava platform at about 2–3 m. above sea-level, indented by clefts to form a series of irregular short projections, backed by a regular cliff about 10–20 m. high. This cliff follows a broad curve around the end of the island and above it smooth debris-covered slopes mount to the crater rim. The west coast of the island, from Salamander Point to Hardy Point, follows roughly a straight line trending north-east to south-west, and it consists similarly of a discontinuous narrow lava platform a few metres above the sea, extending from the foot of a vertical cliff of banded rocks. This western cliff has a maximum height of 55 m. and in places it overhangs for much of this height. Above it, as at Salamander Point, smooth slopes of debris mount to the single cone in the centre of the island. It is only when Hardy Point is reached that the west coast of the island declines and the cliffs end to give a shore of lava reefs and shelves backed by gentle slopes of debris.

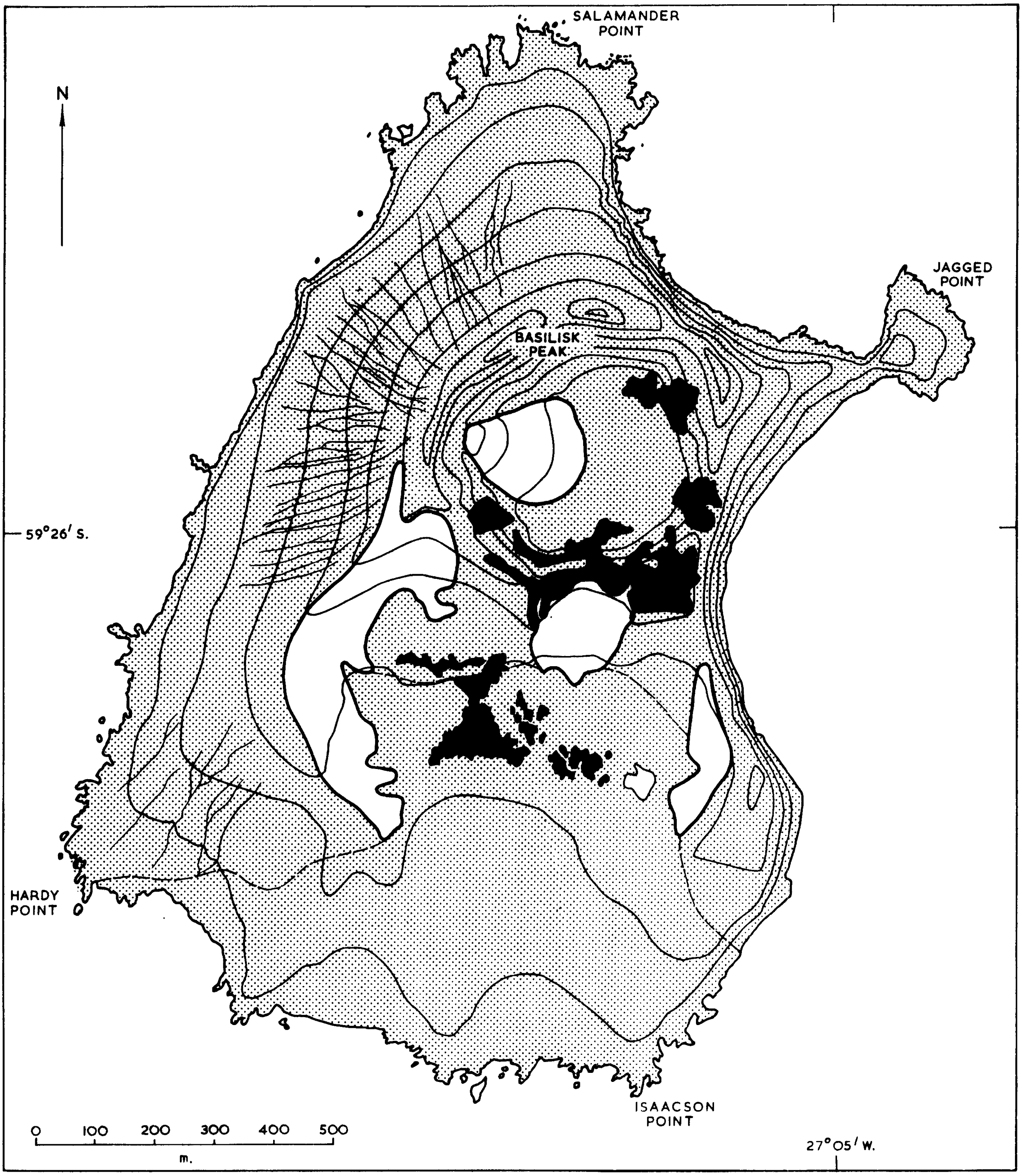


FIGURE 14

Sketch map of Bellingshausen Island. The solid black represents areas of heated ground with vegetation. The pecked line defines the margin of the rough lava area.

Returning to Salamander Point and passing southward along the east coast of Bellingshausen Island, there is a sharp contrast. Instead of the straight run of the west coast with its even cliffs and smooth upper slopes, on the east side the shores of Salamander Point are succeeded by narrow beaches and scattered rocks below the high cliffs of a curved embayment. This bay cuts back into the flanks of the central cone and in its middle part the cliffs fall 180 m. from the summit rim to the sea. Beyond the bay, the coast runs out to Jagged Point, around whose outer flanks a low lava platform is once again visible at about 2–3 m. above sea-level. From this, even slopes begin to mount towards the summit of the island, but two opposing bays on either side of the headland have cut its link with the main mass of the island to a narrow waist and so caused part of the upper section of the ridge above to fall away leaving a square-cut notch from which the point is named. South again from Jagged Point, the second of the eastern bays cuts back into the central cone in cliffs up to 120 m. high and at one point erosion has made a jagged breach. Southward the cliffs swing out again below a subsidiary hill in the south-east corner of the island and diminish until, at Isaacson Point, they are only about 10 m. high. The south coast of Bellingshausen Island, from Isaacson Point westward to Hardy Point, is a series of lava shelves and coarse beaches below low cliffs terminating a slope of irregular basaltic lava.

The inland topography of Bellingshausen Island is comparatively simple. A single volcanic cone with a crater about 500 m. across rises north and east of the centre of the island, the rim around the crater being circular with its highest point, Basilisk Peak, in the north-west and further summits on the north and north-east sides. On the north-east and east the crater rim also forms the crest of the coastal cliffs (except for a fragment of the original outer slopes of the cone on the north-east, preserved as the crest of the ridge running out to Jagged Point). On the north, west and south-west, on the other hand, the outer slopes of the cone fall away regularly from the rim at an angle of about 30°, and are covered by loose rocks and scoria and furrowed by many small drainage channels. The gradient of these slopes slackens lower down and they merge into a slightly inclined terrace above the western cliffs and above Salamander Point.

The southern slopes of the Bellingshausen Island volcano are more complex and also easier in gradient. In the south-west an arcuate ridge runs out from the crater rim towards Hardy Point and then curves to sink into the southern lava plain near its centre. This ridge holds within it, on the east, a broad strip of compacted permanent snow which may overlie a small mass of ice and which is locally crevassed. In the centre of the southern section, the crater rim is lower than elsewhere, and passing southward, its outer slopes descend rather steeply at first to a terrace, traversed by a fissure and flanked by fumaroles, at a little over 100 m. Below this the southern lava plain drops away in an irregular surface of low rough outcrops and scoria- and dust-covered hollows to the south coast. In the south-east of the island, a second ridge runs from the crater rim along the top of the eastern cliffs to the low subsidiary hill above Isaacson Point, and within the arc of this ridge also there are two small snow patches, the upper one filling a depression in the slopes of the main cone and the lower lying close under the eastern ridge. The general configuration of all this area suggests some slumping of the outer slopes of the cone with the development of the terrace and fissures across it, and this is perhaps to be associated with the emission of the rough lower lava-flow system and with the present fumarolic activity in the area.

The inside of the crater on Bellingshausen Island is a circular pit about 60 m. deep (measured from the lowest part of the surrounding rim) with a more or less level debris-covered floor. Although it is a totally enclosed basin, the crater contains no lake and is evidently drained through the porous rocks of the rim or floor. From Basilisk Peak there is a drop of about 180 m. to the floor of the crater. The crater walls, which are decidedly higher around the northern than around the southern half of the crater, have an average slope of about 60° but in places they are nearly vertical. On its west side, rising at a steep angle to a point half-way up the high western rim, is a dome of ice perhaps 100 m. high, culminating in a smooth summit which stands clear of the rock wall. Apart from this, the crater is free from permanent snow.

Bellingshausen Island appears not to have been landed on before *Protector*'s visit in March 1962, when a helicopter deposited a party on the southern slopes of the cone. Despite this, it is relatively easy to land on. In calm weather a boat could be brought in at several points on the southern coast from which the whole island is easily accessible. In March 1964, helicopter landings were made at several points on the southern lava field, on the slopes above Hardy Point and on the terrace above the western cliffs.

The first survey of Bellingshausen Island was by *Discovery II* in 1930 (Kemp and Nelson, 1931). The present map is based on complete coverage of vertical air photographs obtained in March 1964, controlled by triangulation with distance measurements by tellurometer. The height of the summit of the island was determined accurately in the course of this triangulation and it proved to be 253 m. instead of the 160 m. previously suggested.

2. *Geology*

The general stratigraphical succession on Bellingshausen Island is as follows:

6. Isaacson Point basaltic andesite.
5. Hardy Point basaltic andesite.
4. Scoriaceous red agglomerate.
3. Grey tuffs.
2. Pyroclastics of parasitic centre.
1. Older basaltic andesites and scoria beds.

Excellent sections through the main volcanic cone are exposed around the northern coast and in the crater. At several localities three major units may be recognized as forming the visible part of the cone. The approximate thickness of each at various localities is given below:

Locality	*North wall of crater*	*Bay north of Jagged Point*	*Bay south of Jagged Point*	*Salamander Point*
Distance from crater rim (m.)	0	200	275	400
	m.	m.	m.	m.
Red agglomerate	9	6	6	5
Grey tuffs	25	21	12	9
Basaltic andesite lavas with scoria horizons	60+	18		30+

The three units are exceptionally well displayed in the crater walls, particularly on the northern side below Basilisk Peak. The higher parts of the crater rim are invariably formed by the red agglomerate which provides a more resistant capping to the easily eroded tuffs and ashes beneath. Around the southern part of the rim much of the agglomerate has been removed, perhaps as a result of faulting and slumping accompanying the outpouring of lava to the south, and the underlying tuffs have disintegrated into a scree. A few steep-sided tabular relics of the red agglomerate are, however, preserved on the south-western side of the crater. Both the red agglomerate and the grey tuffs generally dip outwards from the crater at an angle of about 30°, but at one point on the western side of the crater their relationship is unconformable with the red agglomerate dipping outwards at 30° overlying grey tuffs which here dip inwards at about 10°. This is probably a local slumping phenomenon with part of the grey tuff group having been tilted from its original attitude back into the crater before the deposition of the red agglomerate.

Much of the red agglomerate has been stripped from the Jagged Point promontory and only isolated slabs of it remain along the crest of the ridge, where erosion is rapidly removing the underlying tuffs. The fan-shaped headland of Jagged Point itself survives on account of the protection given by a lava at the base of the cliffs.

The great cliffs in the vicinity of Salamander Point show a similar but somewhat thinner succession compared with that in the crater walls. The main difference is in the lowest of the three units. Whereas in the crater this unit is mainly massive lava, at Salamander Point there are many scoria horizons interbedded with lava flows; red scoria fragments are often incorporated in the base of an overlying flow. Although scoria beds with thin flows predominate at the base, thicker lava flows tend to prevail in the higher part of the succession. In one instance a flow about 20 m. thick appears to be filling a valley with a great lobe of lava which bulges downwards, apparently truncating the interbedded scoria and lava sequence. This scoria and lava sequence is found only in one locality in the crater where it makes a conspicuous bluff protruding from the wall on the west-south-western side.

The red agglomerate consists for the most part of closely packed blocks of reddish vesicular lava around which are smaller fragments of similar scoriaceous material; accessory blocks of compact andesitic lava are common, ranging up to as much as 30 cm. in diameter. The agglomeratic deposit is poorly compacted but loosely welded, making a moderately stable yet very porous formation; the larger blocks often show a neatly interlocking relationship and individual blocks are frequently intensely fractured but not greatly dislocated. In places, notably below Basilisk Peak and on the south-west side of the crater, the agglomerate appears to grade upwards into a vesicular reddish lava.

The widespread distribution of the red agglomerate around the crater indicates that it is a pyroclastic deposit, yet in some places, especially in the top metre or so, it is relatively homogeneous and more massive with more the character of a flow. It has perhaps formed from a fire-fountaining process when for much of the time the fragments were fairly viscous on impact but just capable of welding. At times, lava flows may have formed locally as driblets from the fire fountains and there may have been accompanying outbreaks of more substantial flows in the closing phases. It is just possible that at the beginning of the eruptive episode the hot scoria fell in places on to ice or snow, the rapid vaporization of which resulted in the disruption of the accumulating deposit.

The grey tuff group is actually composed of innumerable thin beds each 30 cm. or so in thickness; although some beds are rather poorly compacted tuffs, many are virtually unconsolidated ash bands. Their differing susceptibility to erosion is the reason for the slight variation in relief of different bands on a cliff face, which so strikingly emphasizes the regular and persistent stratification. This is especially conspicuous in sections in the crater wall and along the Jagged Point promontory, where the beds sweep down from the crater rim to the sea. Black and red cinders, and ash coated with a pale buff-coloured dust, comprise the bulk of these beds.

The lowermost formation consists of thick andesitic or basaltic flows in places interbedded with basaltic scoria and thin driblet flows.

The thick flow forming the lower part of the northern half of the crater floor is a fine-grained greenish grey basaltic andesite containing phenocrysts of plagioclase and occasional clinopyroxene in a groundmass of plagioclase microlites, granular pyroxene and magnetite. The lavas exposed at Salamander Point are apparently of a similar mineralogical composition.

Only one parasitic eruptive centre has been recognized; it forms the small hill on the south-east coast, about 400 m. to the north of Isaacson Point. Marine erosion has removed part of the hill to expose red ash, cinders and lapilli dipping at 20° to the south-east and this is unconformably overlain by the grey tuff and red agglomerate from the main cone.

The youngest part of Bellingshausen Island is formed by the lava flows which occupy the rugged but generally low terrain to the south of the crater. The oldest of these flows is probably that which crops out near sea-level at Hardy Point, and the youngest is almost certainly that which forms the extensive area between the fumaroles on the south slope of the cone and the south coast. The latter has been termed the Isaacson Point basaltic andesite. The Hardy Point basaltic andesite forms cliffs up to 12 m. high in places along the south-west coast, but at Hardy Point itself it appears as a low wave-cut platform with irregular promontories extending from the base of the cliffs. In places on this platform the flow has the character of bolster or entrail lava (Rittmann, 1962, p. 66). Erosion has sometimes exposed a longitudinal section through a lobe revealing an outer shell of vesicular lava with the vesicles elongated parallel to the long axis of the lobe. Lobes with this concentric structure possibly formed as the lava passed out into the sea. 200 m. to the north of Hardy Point the lava cliffs show unusually distinct vertical and horizontal jointing giving the cliff face the appearance of a coarse dry-stone wall. The lava is overlain by as much as 12 m. of tuff and ash, much of which appears to have been re-distributed. About 365 m. to the north of Hardy Point another basaltic lava appears at the top of the cliff, above the ash and the Hardy Point flow; this lava also crops out intermittently along the crest of a ridge which runs up the south-west flank of the cone. Relationships become more obscure higher up on the south side of the cone where the various flows seem to converge. More lava appears *in situ* in the walls of the fissure which trends across the southern side of the cone but it is not clear to which, if any, of the other flows this belongs.

The last major event in the development of the Bellingshausen Island volcano was the emission of the Isaacson Point basaltic andesite which is best exposed in the sea cliffs and their immediate hinterland along the south coast of the island, where natural arches and caves have been cut into the rocky promontories. The upper part of the flow is a vesicular and somewhat glassy aa lava with occasional pahoehoe patches but this passes down into a paler and more compact rock which is well exposed and accessible from the shore to the south-east of Hardy Point.

The various flows which form the southern part of Bellingshausen Island can scarcely be distinguished on petrographic grounds. All of them contain small phenocrysts of calcic plagioclase and clinopyroxene in a groundmass of plagioclase laths, granular pyroxene and magnetite. These flows may well have been emitted in fairly rapid succession and some of the features singled out as separate lava flows could, in fact, be different lobes of the same flow. Not only are the southern lavas similar to each other but they are also closely comparable with the older lavas found in the north and in the crater. In the hand specimen, the lava from the lowest part of the crater wall has a greenish colour, giving it a rather different appearance from any of the other flows. Blocks of this lava are found loose on the outer slopes of the cone and xenoliths of the same material are found in fine-grained to glassy blocks of the Isaacson Point basaltic andesite, especially in the more northerly part of its outcrop. In thin section, however, the greenish lava appears much the same as any of the other flows with perhaps slightly fewer opaque constituents.

The youthful form of the Bellingshausen Island volcano and the restriction of activity to a single centre, with the exception of one parasitic cone, together with the appreciable fumarolic activity suggest that the island is one of the most recent to have developed within the South Sandwich Islands group. The close petrographic similarity of all the lavas examined and the chemical resemblance of the analysed specimens suggest that the entire island has probably formed in a relatively short period of time; none of the other islands investigated in any detail possesses such a limited range of rock types.

3. *Fumaroles*

Fumarolic activity on Bellingshausen Island was first noted from *Discovery II* in 1930, when steam was seen rising from below the inner lip of the crater and from a fumarole high on the south-eastern slopes. This was again the general situation in 1962 and 1964. The island retains numerous active fumaroles, which fall into two groups. The more vigorous type emits sulphurous fumes as well as steam, and the areas around the vents, which commonly open as single or multiple apertures among boulders, are encrusted by yellow sulphur deposits. This type of fumarole is definitely hotter than the second type, ejecting steam only, and the differences in heat and perhaps in the nature of the emitted vapour are reflected in the vegetation. The steam-emitting fumaroles themselves vary widely in character, ranging from single or clustered vents with broad mouths among rocks (most characteristically among piles of rocks like small broad cairns) through single or clustered vents with broad mouths in shallow depressions among finer debris to narrow cracks, often of considerable length, traversing ash and scoria slopes. Some areas, both among rocks and on ash slopes, have no visible vents, but they are evidently warmed from below and may steam gently over a wide area. Finally, there are extensive patches of warmed ground where snow does not lie but where no emergent vapour is visible.

The main fumarole group on Bellingshausen Island lies both within the crater on its southern wall and on the outer flanks of the south side of the cone. Inside the crater the lowest group of fumaroles lies along a narrow fissure traversing the debris slopes of the south-west sector of the wall about 15 m. below the crater rim. This group has declined in activity since the island was visited in March 1962 and was emitting far less steam in 1964 than 2 years before. Two small, rather isolated fumaroles are situated about half-way up the wall on the east-south-east side of the crater. Steam issues through a multiplicity of tiny vents and a few larger ones among the rocks of a small buttress on the south-west of the crater, and along the low cliffs which cap the southern crater wall. More definite fumaroles break out in the south-east corner of the crater, high up near the lip, and here, in a small subsidiary hollow, steam-emitting vents on the west give way to sulphur-emitting vents on the east. These last were more active in 1964 than when the island was visited in 1962, and patches of dead encrusted vegetation about them were conspicuous.

Outside the crater there are scattered fumaroles high up on the southern slopes, and a more prominent group on a terrace at about 100 m. aligned along a prominent fissure. This group was the subject of detailed study in 1964 and was also the site of collections in 1962; activity had changed little in that period. The fissure trends in an east-north-easterly direction for about 500 m. at a distance of about 140 m. from the crater rim. The central part of the fissure is obscured by an area of snow and ice. At its western end, the fissure is about 6 m. deep and runs along the top of a conspicuous rocky bluff on which the active fumaroles are located. Patches of vegetation on the hummocky ground to the south and south-east of this bluff indicate that fumarolic influence affects this area also, although at a low level of activity.

The fissure re-appears to the east of the ice mass, widening into a trench cut in red agglomerate about

90 m. long, 30 m. wide and as much as 18 m. deep on the northern side. Sulphurous fumaroles occur both around the edges and on the floor of the trench. In March 1964, the most vigorous fumarolic activity on the island was concentrated in this trench and on the part of the crater rim immediately above it; one of the fumaroles at the western end of the trench was emitting vapour in distinctly audible blasts.

Lower down the southern slopes, below the well-marked terrace where the main cone slopes merge into the lower basalt platform, there are a few small fissure-type fumaroles but extensive tracts of warmed and rather ill-vegetated ground. Isolated small fumaroles and warm spots also occur at many points on the undulating basalt platform itself.

4. *Vegetation and fauna*

Bellingshausen Island, despite its position near the southern end of the South Sandwich Islands group, has a relatively rich vegetation. This is especially well developed about fumaroles, where concentric zones of mosses and hepatics are present; these have been studied in detail and will be described elsewhere (Longton and Holdgate, 1979). Away from fumaroles, moss patches are to be seen in places on the flanks of the cone where melt water percolates, and some of the higher and more stable rocks are well covered by lichens and tufts of moss. All of this vegetation and soil has a considerable fauna of mites and Collembola (Tilbrook, 1967*a*, *b*, 1970). About the penguin colonies on the south and west slopes there is much *Prasiola*.

Bellingshausen Island, although one of the smaller islands, has a comparatively rich avifauna. Most numerous, as in the other islands in the South Sandwich Islands group, are chinstrap penguins (*Pygoscelis antarctica*), which nest all along the lava plain in the south and along the slopes above Hardy Point. Among these birds are found small scattered groups of macaroni penguins (*Eudyptes chrysolophus*), there being about 100 pairs on the island. The penguin colonies are mostly small and very scattered, making estimation of numbers very difficult; there are probably about 5,000–6,000 pairs of chinstrap penguins on the southern plain. One might reasonably expect to find Adélie penguins (*Pygoscelis adeliae*) breeding on the island, but at the time of the 1964 investigation any chicks would have completed their moult and left the island. Many mangled corpses were examined but none was positively identified as *Pygoscelis adeliae*.

Skuas were abundant on the island and several had nests on the lava slopes to the south of the crater. The chicks were in the process of obtaining their adult plumage and some were just capable of flying a few yards. Gulls (*Larus dominicanus*) were equally abundant and many had nests among the penguin colonies on the south coast.

Wilson's petrels (*Oceanites oceanicus*) were found nesting on the cindery slopes near Hardy Point and a few burrows were dug out to reveal single fluffy chicks, occasionally accompanied by an adult bird. Snow petrels (*Pagadroma nivea*) are thought to breed as a number of wings were found scattered about the crater rim, the "left-overs" of a skua's meal. Other remains found were of the dove prion (*Pachyptila desolata*), usually in the vicinity of a skua nest.

Giant petrels (*Macronectes giganteus*) were seen resting on the southern lava slopes but no nesting sites were found on the island. Cape pigeons (*Daption capensis*) and fulmars (*Fulmarus glacialoides*) were seen flying around the island in small numbers but there are no known nesting sites.

In March 1962, about 25 fur seals were seen on the south-west coast of Bellingshausen Island. In 1964, seven male fur seal were found on Hardy Point but there were no females or pups, and it is thought that Bellingshausen Island is not a breeding area. One elephant seal was seen on a southern beach and also a single Weddell seal. Two leopard seal and a single crabeater seal were seen at sea.

J. Cook Island

1. *Topography*

The coastline of Cook Island (Fig. 15) is the most precipitous of any in the South Sandwich Islands group. In outline, the island is nearly rectangular, the north and south coasts being almost exactly 6 km. long and aligned almost due east–west; and the east and west coasts, which run very nearly along a true north–south bearing, measuring about 3·5 km.

Like Montagu Island, Cook Island has no well-marked north point. From the great cliffed bluff of Tilbrook Point in the north-west corner of the island, where a rock wall capped by ice rises about 250 m.

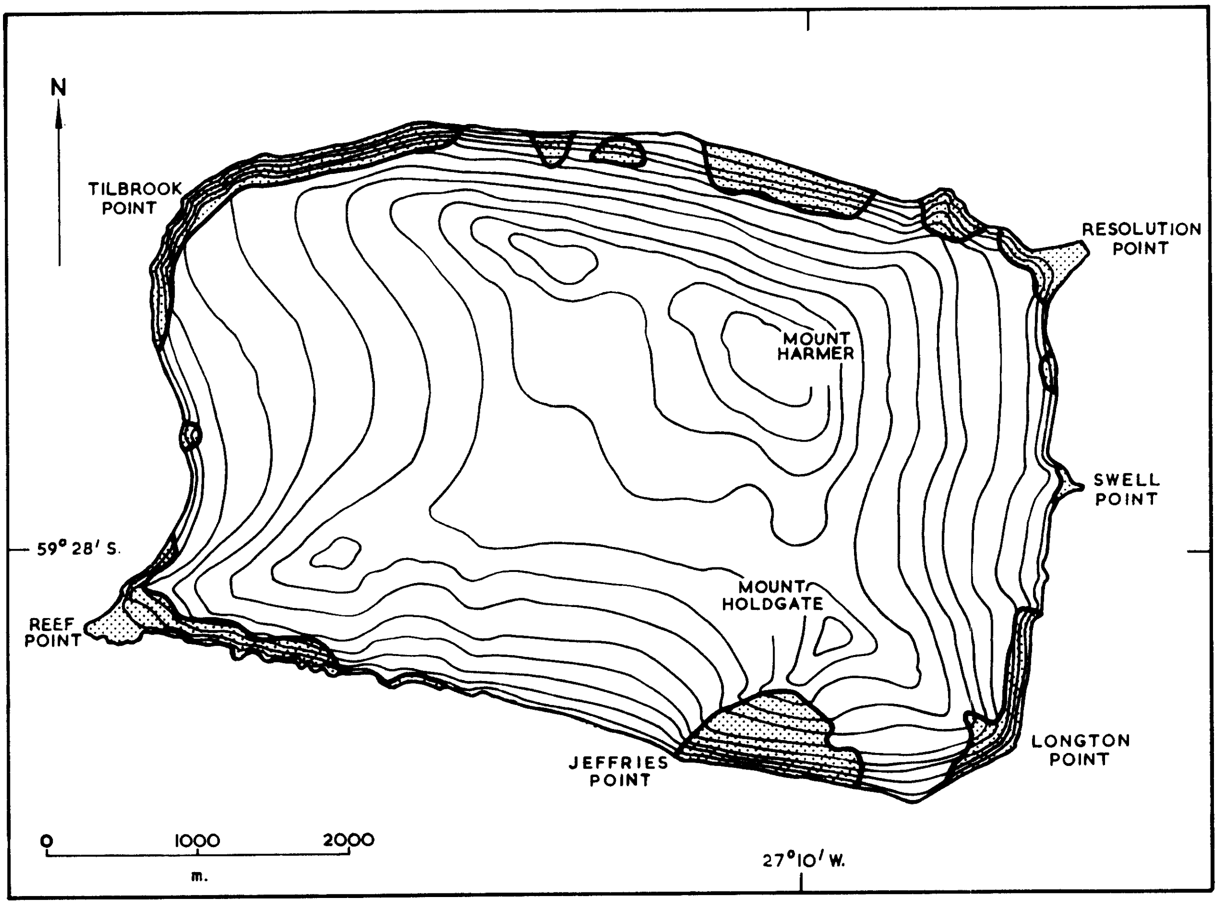


FIGURE 15
Sketch map of Cook Island.

from the sea, the coast trends eastward with but a gentle convexity. Along this coast the cliffs and ice falls above mount steadily in height until in its centre they fall almost unbroken from the upper ridges of Mount Harmer and a nameless crest to the west of it. There are two distinct glaciers descending to the sea along this coast, and between them areas of rock and hanging ice with talus fans below, but there are no beaches apart from occasional masses of piled boulders and debris.

In the north-east corner of the island the rock walls below a buttress of Mount Harmer swing out around a small cove to a high blunt-nosed headland and then curve about a second embayment to the jutting platform of Resolution Point. This point, which is the north-eastern corner of Cook Island, is a relatively flat-topped and low-lying lava mass, surrounded by cliffs about 50 m. high lying as a step below the high wall of the mountain. To its south a steep and broken glacier descends to the sea, divided at its snout by a small rock buttress, and beyond this glacier the coast projects slightly in a second pronounced rocky headland, Swell Point. In profile this headland has a stepped form, a terrace of rock and ice about 75 m. above the sea falling sharply to a short flat-topped projection at around the 15 m. level, after which a further vertical drop leads to the terminal section of the point, a narrow reef only 2 or 3 m. above the water.

South of Swell Point, a second glacier falls sharply from the eastern face of the main mountain mass to the sea, coming to the shore in vertical ice cliffs 50 m. high. The southern end of this glacier is marked by a slight promontory from which rock cliffs run as a wall about 150 m. high to Longton Point. Here, below a ridge running from Mount Holdgate the high cliffs bend south-westward and decline as they run out to a second point, which marks the true commencement of the south coast of the island. This point is formed of the snout of a very steep and tumbled glacier falling from the south face of Mount Holdgate and beyond a short section of ice cliff the coast again becomes rocky, being formed of sheer cliffs cut through the south-west buttress of the mountain. At their highest, these rock cliffs are about 450 m. above the sea and they run westward for about 1·25 km. before giving way again to ice.

Between the termination of these cliffs and a point about 2 km. east from Reef Point in the south-west, the south coast of Cook Island, along a distance of 2 km., is almost wholly formed by ice cliffs at the foot of a steep slope of glacier falling from the main mountain mass. These ice cliffs are about 50–75 m. high and show local small rock exposures below them; in the centre of their run they are interrupted by a short stretch of cliff overhung by ice. Somewhere along this coast must be supposed to lie the point named "Jefferies Point" by Kemp and Nelson (1931) but this cannot be located with certainty, and radar-screen photographs show no projection of the land in the area where photograph captions and sketches in the 1931 report indicate that the point should lie. The glacier cliffs continue rather evenly westward until, at 2 km. from Reef Point, they swing out and end against rock cliffs which fall from a hill in the south-west corner of the island. These cliffs rise in two places to heights of around 300–350 m. and, seen from seaward, they are conspicuous because at either end they rise to conical horns with a broad saddle-shaped central hollow capped by an ice cliff. Near the point at which coastal glacier and cliff meet there is a small but conspicuous elongate off-lying rock, and the coast below the saddle-shaped cliff mass is irregular and has minor rocky headlands alternating with stretches of boulder beach. Both these and the high cliffs come to an end westward at Reef Point, a lobed tongue of lava projecting south-westward at the corner of Cook Island, towards Twitcher Rock and Hewison Point on Thule Island beyond.

Reef Point has a flat surface cut off on three sides by sheer sea cliffs 25 m. high. It projects 350 m. from the foot of the mountain, and the slopes rising above it do so with a rather smooth concavity, steepening as they ascend. North of the point the sea comes in to a short bay with a coarse shingle beach and a conical stack just offshore. The cliffs increase sharply in height from the point of junction between headland and main mass; at the nose of rock north of the bay, they stand about 100 m. above the sea and round the corner they are higher still. They cut the western slopes of the subsidiary hill in the south-west corner of Cook Island and give way to a glacier farther north, where the west coast of the island swings round in a broad curve walling-in this side of Douglas Strait. This glacier drains from the main mountain mass of the island and falls to the sea in ice cliffs which are now at their southern beginning but rise to the north and, passing upward eventually come to lie above the rock cliffs forming the basalt levels of the great north-western bluff of Tilbrook Point.

The interior of Cook Island, although imperfectly surveyed, has been recorded by various photographs. The main ridges of the island run above the north and east coasts, and several summits rise upon them. Above the north coast there are two peaks, the westernmost and lower attaining about 1,000 m., and the easternmost, Mount Harmer, which stands at the junction of the northern ridge and that above the east coast, rising to 1,075 m. The eastern ridge running south from Mount Harmer has three summits, Mount Harmer itself being counted the first and northernmost of these. The central summit on the eastern ridge is a knoll of no great prominence probably reaching about 915 m. with a subsidiary ridge trending south-west from it, while the peak in the south-east angle of the island, Mount Holdgate, at which the ridge terminates, is a prominent mass about 945 m. high. On their outer faces, i.e. the northern and eastern, these ridges and peaks fall to the sea in steep slopes mostly covered in tumbled crevassed glaciers. Within the angle between the two ridges, however, in about the centre of the island, the upper slopes appear to be less abrupt, and there is a broad hollow containing a high ice field. This is partly enclosed to the south by the subsidiary spur that runs south-west from the central knoll on the eastern ridge, and it probably drains mostly westward into the glacier system falling to Douglas Strait. Some ice, however, flows around and over the spur and joins with the glaciers that fall from Mount Holdgate and the central eastern summit to the south coast. As on the north and east, the south and west faces of the peaks are wholly ice-covered and the heavily crevassed ice cap extends over ridges and hollows alike.

Its precipitous coastline makes Cook Island one of the most difficult to land on in the South Sandwich Islands group, and there is no point from which easy overland travel is possible. There is no record of any landing before 1964, when a helicopter from *Protector* put parties ashore at Reef and Resolution Points; these are probably the only easy landing places for such aircraft.

Cook Island was first surveyed by *Discovery II* in 1930 (Kemp and Nelson, 1931), and radar-screen photographs obtained in 1964 show that the coastline they drew was tolerably correct except in the north of the island which is far less convex than was thought. This north coast is even less accurately represented on Argentine Chart 111 (corrections to 1958), but the south and east coasts have been improved in detail on that document, although not plotted to the correct relative scale. Local triangulation with tellurometer lines was established within the Southern Thule group in March 1964, and provided control for the present map, the coastline of which has been taken from radar-screen and oblique air photographs. Interior detail has been sketched, while heights cited are based on helicopter altimeter measurements in March 1962. Considerable uncertainties remain concerning the inland topography of Cook Island and there is some ambiguity over which summit is actually that named "Mount Harmer" by Kemp and Nelson (1931); in their account they stated it was the northernmost of three summits above the east coast and this usage is retained here. In 1962, its identity was questioned largely because the western peak of the island above the north coast was not mentioned or sketched in the *Discovery II* survey, and it was assumed to be the northernmost peak of the island and was clearly lower than its neighbour (Holdgate, 1963).

2. *Geology*

Kemp and Nelson (1931, p. 186) regarded Cook Island as the relic of a much larger island which included Thule Island, and they considered that the material forming both of these islands originated from a large crater which is now below Douglas Strait. Unfortunately there is very little geological information about Cook Island but at least it would appear from the dip of the beds that the lavas and pyroclastics exposed in the cliffs east of Reef Point originated from a source within the south-western part of Cook Island itself. The general configuration of Cook Island also suggests that it is formed by a number of closely associated volcanic centres, of which the main one is Mount Harmer. However, there is little to support the view that the island has been constructed from a crater which lay to the west.

Geological collections were made only on the 25 m. high promontory running out to Reef Point. This feature is part of a dark dacite lava flow, the surface of which is strewn with blocks derived from the steep slopes behind. The flow is not an old feature projecting from the base of the cliffs but is apparently of relatively recent origin and may have descended from the flanks of the south-western peak of Cook Island which is probably a subsidiary eruptive centre. Although the uppermost part of the flow is reddish in places, in general it has a fresh appearance and is dark grey in colour. The lava was examined only near the top of the headland where it appeared to be finely vesicular throughout and has a persistent flow banding. The dacite is essentially aphyric but microphenocryts of plagioclase may be seen in thin section. The spherulitic structure of the lava also becomes evident under the microscope; pale grey blebs of microcrystalline to cryptocrystalline material are packed with varying concentration into a pale brown glassy base. Microlites of plagioclase and clinopyroxene are larger and more abundant in the glassy parts of the groundmass. A very thin dyke is well exposed on the northern side of the Reef Point promontory where the surface of the platform begins to steepen up towards the main part of the island. Although the dyke rock is mostly dark and aphyric, an occasional feldspar phenocryst can be seen in the hand specimen. In thin section, the rock shows a strongly banded structure, the apparent differences being due to variations in the colour of the base which ranges through various shades of brown and black. Apart from the larger plagioclases, the andesite is composed of plagioclase and clinopyroxene microlites, magnetite and glass.

Many of the blocks forming the thin layer of debris on the surface of this platform are of coarsely porphyritic basalt, in which large phenocrysts of olivine, pyroxene and plagioclase are very conspicuous in the hand specimen. These blocks have presumably been derived from a source in the south-western part of the island.

There is no record of any volcanic activity on Cook Island.

3. *Vegetation and fauna*

Cook Island probably has an exceptionally sparse land flora even by the standards of the South Sandwich Islands group. Lichens, especially of the encrusting kind, undoubtedly occur on rocks as on Reef Point and Resolution Point but no specimens have been collected. Owing to the sheer coastline, penguin and seal colonies are probably absent, but Kemp and Nelson (1931) reported large numbers of fulmars (*Fulmarus glacialoides*) on the cliffs above Douglas Strait. From *Protector*'s helicopter, Lt J. Barr observed many fulmars on the northern and western coasts between Resolution Point and Reef Point in March 1964, while east-south-east of Reef Point both fulmars and cape pigeon (*Daption capensis*) occurred but were very much less numerous.

K. Thule Island

1. *Topography*

Thule Island (Fig. 16) is the southernmost of the South Sandwich Islands group, and it lies at the western end of the line of three southern islands. It is an irregularly triangular island, measuring 5·2 km. from the north coast to Herd Point on the south, and 5·4 km. between the western headland of Cape Flannery and Beach Point in the north-east corner. The highest summit, Mount Larsen, attains 725 m.

As at Cook Island, there is no well-defined northernmost headland. Beach Point, in the north-east of the island, is the most prominent feature in this area, consisting of a rounded tongue of boulder beach which laps the base of a low rocky ridge about 400 m. long and 50 m. high. Near the end of the ridge, just before it sinks to the boulder beach, there is a detached obelisk of black rock about 7 m. high, conspicuous from north and south. The north coast of the Beach Point ridge is cliffed and the cliffs increase in height westward as the ridge merges with a small ice-covered peak which stands in the north-east of the main island. Under this peak the coast, which bulges northward, is formed by rock cliffs about 150 m. high; farther westward, as they begin to curve more to the south, these cliffs become higher still and are capped by ice falls which terminate the ice cap of Mount Larsen.

At their highest, the rock cliffs of the north coast of Thule Island rise about 300 m. from the sea in stratified and terraced walls with the ice above them. The coast as a whole trends broadly to the west-south-west

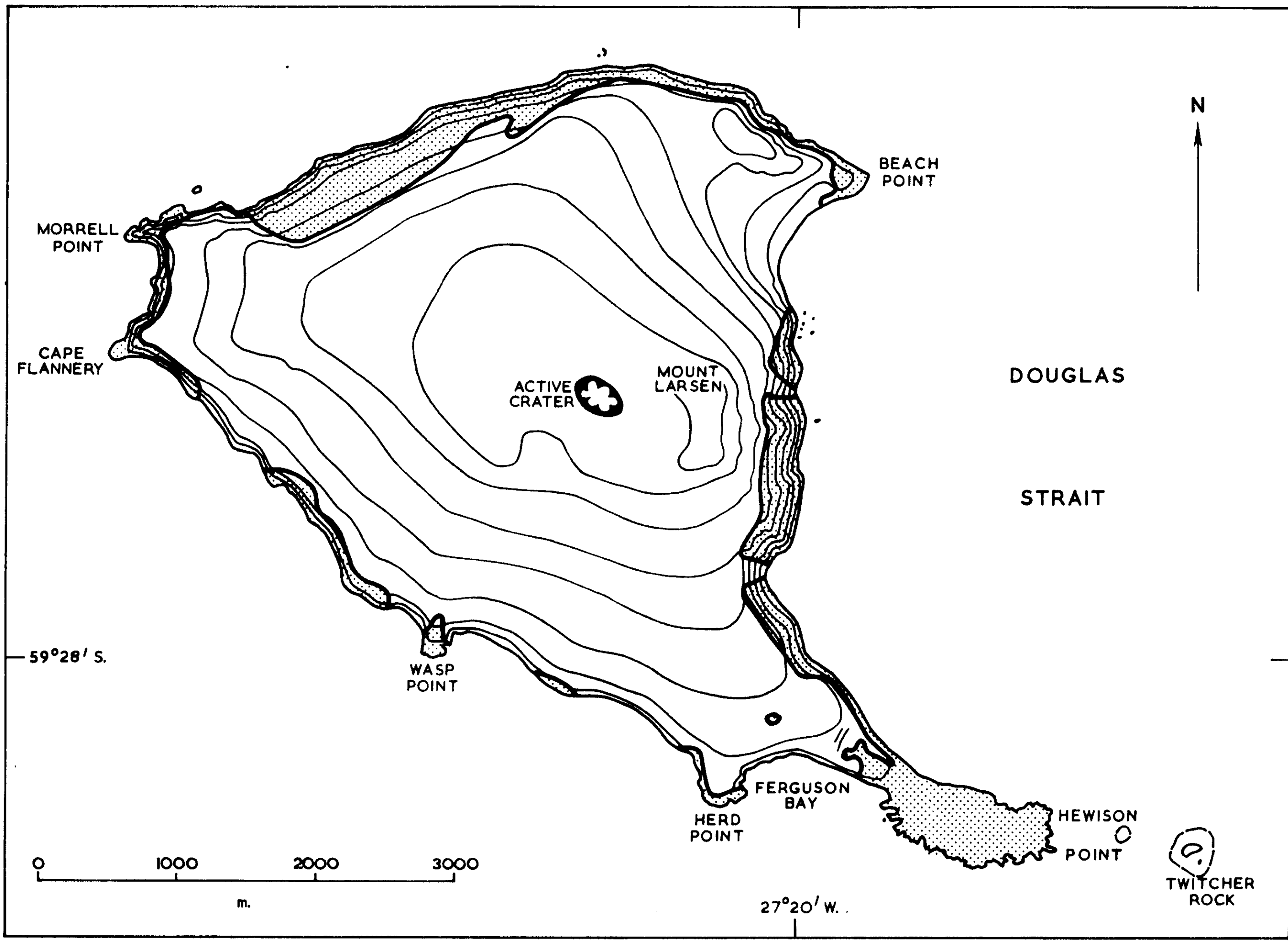


FIGURE 16

Sketch map of Thule Island.

and along it there are a few small off-lying rocks, the largest lying about 100 m. out to sea just before the north-western headland of Morrell Point. Just at this place, opposite the rock, a mass of ice descends almost to the coast, marking the edge of the north coast ice falls. Morrell Point itself is a nose of lava with rather even cliffs about 100 m. high, capped by a sloping terrace of talus below uniform ice cliffs which rise a further 50 m. Around the point there are reefs and rocks, and beyond it the coast recedes in a bay 0·8 km. across, whose farther point is Cape Flannery, the western extremity of Thule Island. The cliffs of the bay and Cape Flannery are of lava, about 75–120 m. high with ice cliffs above, and at their feet are a few areas of boulders and small off-lying rocks, but no beaches. Off the nose of Cape Flannery there is a reef a few metres above sea-level, extending as a tongue over 100 m. from the base of the cliff.

The long south coast of Thule Island trends in a south-easterly direction from Cape Flannery and consists of alternating shallow headlands and indentations of no great prominence, formed of similarly alternating rock and ice cliffs. The banded terraced cliffs of Cape Flannery extend for about 1 km. along the coast; then comes a short glacier with 50 m. ice cliffs; then a long rock exposure surmounted by ice cliff and a further small glacier. Some of the glacier hereabouts was in 1962 conspicuously blackened by ash. 3 km. from Cape Flannery the south coast runs out to a fairly prominent feature, a short rocky point with a ridge running inland perhaps 100 m. before it vanishes under the glacier. This is Wasp Point which is followed by a long bay of ice cliff with one small rock outcrop under the ice in the centre, and then the coast again swings out to a lava headland, Herd Point, which is a square-cut promontory about 300 m. long and wide. This is a fairly distinct feature with a long even slope of ice running out to the apex of the headland and giving way to a low-lying platform of lava perhaps 10 m. above the sea.

East of Herd Point is a pronounced bay, Ferguson Bay, which is almost 1 km. across and cuts about 400 m. into the land. The bay is well known because Kemp and Nelson (1931) considered it the best anchorage in the South Sandwich Islands group, and it has been mapped on a large scale as an inset on various charts (Admiralty Chart 3593; Argentine Chart 111). In practice, since it lies open to the prevailing south-westerly and westerly swell, and gives little shelter, its use to vessels is limited. It is flanked, from Herd Point eastward around its head, by low ice cliffs which give way in the east to the broad low headland of Hewison Point. This, the most prominent headland on the island and one of the most striking in the South Sandwich Islands group, is a lava platform reaching to about 30 m. above the sea, having the form of a slightly tilted block. its highest crest lies along its north side, where sheer cliffs fall into Douglas Strait, whereas on the south the debris-covered surface of the platform sinks gradually to a coast of inclined rock shelves. In outline Hewison Point is an irregular oblong 1·1 km. long and 0·4 km. across, and its eastern, southern and western coasts are irregularly divided by clefts and recesses into a multitude of small promontories. A few small knolls rise from the surface of the platform, especially near its landward end, and one of these is surmounted by a beacon of metal lattice work, while an Argentine refuge hut, "Teniente Esquivel", stands in a hollow between two knolls near the junction of the headland with the main island. At this junction, the neck of the point is only 250 m. across and flanked on both sides by boulder and shingle beaches. Above it, slopes of reddish cinder mount to the shoulder of the main island, ending in a series of knolls about 75 m. above the sea, surrounded by snow, and not far below two prominent bars of moraine which lie transversely across the shoulder of the island.

East of Hewison Point, which marks the south-east corner of Thule Island, about 1 km. offshore, there is an isolated conical stack, Twitcher Rock, rising about 80 m. from a reef over which the sea washes. North of Hewison Point, the east coast of Thule Island swings westward in a broad curve above Douglas Strait, emerges again to a series of slightly projecting buttresses and then sweeps in a smooth curve out to Beach Point. Rock cliffs overtopped by sheer faces of ice, mount steadily from the base of Hewison Point northward, and the buttresses that fall from Mount Larsen, in the middle of the bay, show rock exposures almost to the summit of the island, over 600 m. above the sea. In two places, steep ice falls tumble down these cliffs. Only beyond the buttressed section of the coast, which is flanked by numerous small offshore rocks, do the cliffs sink in height again and give way to low slopes of ice about the curved bay leading to Beach Point.

In its inland topography Thule Island is very simple. One large volcanic cone occupies the centre of the island, mounting in fairly uniform slopes from above the coasts. On the east the coastal cliffs are cut into this cone almost to its crest; on the north its slopes are also truncated; elsewhere even slopes of crevassed glacier decline regularly to the sea cliffs. As a whole the slopes of the cone steepen somewhat towards the summit and then give way to a wide plateau about 1·5 km. across. This plateau is not absolutely level; in the south-west, south-east and north it is overtopped by minor mammillations, the northernmost being the actual summit of Mount Larsen, and in the south-west the lip of the plateau is incised by a valley.

The summit plateau of Thule Island is imperfectly known, having only once been studied briefly from a helicopter, but on that occasion (March 1962) it was found to lie about a central crater about 60 m. deep, surrounded by sheer rock and ice cliffs and containing a pool of emerald-green water. The location of this crater on the summit plateau and its relation to mapped features is unknown.

Thule Island has been landed on several times. The first recorded visit was by a whaling expedition in 1911; in 1930 a party from *Discovery II* landed by boat at Beach Point (Kemp and Nelson, 1931). In 1954–55, an Argentine expedition landed and built the hut on Hewison Point and in 1955–56 this was re-supplied and occupied for two summer months. In 1956, *Protector* landed a party by helicopter at Hewison Point and another visit was made to the same area from *Protector* in 1962. In 1964, helicopter landings were made at both Beach Point and Hewison Point; the latter is probably one of the best landing places in the whole island group. As at the other islands, however, severe turbulence was encountered on the lee side of Thule Island in a moderate wind.

The survey of Thule Island from *Discovery II* in 1930 correctly indicated the broad form of the island, although it was inconsistent in detail and especially incorrect in the Hewison Point area. The present map (Fig. 16) is based on vertical air photographs of Hewison Point and Ferguson Bay, and photographs of radar-screen records of the coastline elsewhere around the island. Interior detail has been sketched from oblique air photographs. The height of the island was cited as 710 m. by Kemp and Nelson (1931), and sextant angles from *Protector* supported this determination in 1962, but a helicopter altimeter reading during a flight around and over the summit plateau gave 725 m. Since the highest point probably stands some way back from the plateau lip, the latter value has been taken as the more correct for the present.

2. *Geology*

Stratified pyroclastics and lava flows are exposed in the sea cliffs around Thule Island; the more prominent headlands such as Cape Flannery and Hewison Point are built of the more resistant or perhaps more recent lava flows, whereas the high cliffs along the eastern coast overlooking Douglas Strait appear to be composed largely of pyroclastics.

The island is apparently a partly eroded stratovolcano whose form suggests that the main crater was situated in the area of the summit plateau to the west of the peak of Mount Larsen. The accumulation of snow and ice in this area has obscured its true form but a recent revival of activity evidently resulted in the development of the small crater first observed in March 1962. In the course of the 1964 survey, geological specimens were collected from two areas only: Hewison Point and Beach Point.

The ridge running out to Beach Point had already been investigated in 1930 by members of the *Discovery II* expedition and the specimens collected were subsequently described by Tyrrell (1931, p. 191–97), who reported that the succession from the top of the 50 m. ridge downward is andesite tuff, andesite lava and dacite lava. In the course of the present investigation, however, it has become evident that the lowest lava exposed at the base of the cliffs on the northern side of the Beach Point headland is in fact an olivine-andesite of the type referred to by Tyrrell (1931, p. 193).

The following succession was recorded in the north-facing cliff about 250 m. west of Beach Point:

	m.
Red scoria and ash	12
Brown ash	18
Pale ash	6
Brown ash with orange bands	9
Lava	12
Red scoria and agglomerate	6
Lava (olivine-andesite)	5

A little farther eastward, about 100 m. from the end of the headland, the olivine-andesite lava is no longer present at the foot of the cliffs; instead the succession is:

	m.
Red ash and agglomerate	6
Grey and brown tuffs and ashes	13
Porphyritic basalt lava (probably *in situ*)	1

The basalt at the base of the cliff is a dark grey plagioclase-phyric rock containing smaller phenocrysts of clinopyroxene, olivine and hypersthene. Unfortunately, the dacite lavas, which Tyrrell (1931) reported were collected from a steep escarpment about 15 m. above sea-level were not examined on this occasion. It is possible, however, that the flow above the olivine-andesite and red scoria in the section 250 m. from Beach Point is the source of one or more of the dacite specimens collected in 1930.

The form of the prominent platform leading out to Hewison Point has been described on p. 65; it is built of a flow of dark basaltic andesite together with a small number of loose blocks of other lavas scattered across its surface; these may be morainic debris. The basaltic andesite is for the most part very fine-grained, although there are scattered microphenocrysts of plagioclase and occasional glomeroporphyritic clusters of plagioclase, clinopyroxene and olivine, which are generally inconspicuous in the hand specimen.

The origin of the lava forming this platform is unknown, although it seems likely that it issued from a centre in the south-eastern part of the island. The form of the lava platform may have been largely predetermined by the existence of an area of shallow water on the site. It is possible that the platform has undergone some subsequent movement; the higher steeper cliffs on its northern side and the absence of any significant cliffs on its southern side suggest that there may have been tilting to the south.

Included amongst the blocks on the surface of the platform is a rather pale basalt with phenocrysts of plagioclase, olivine and clinopyroxene.

The glacier extending down on to the isthmus which joins Hewison Point to the main part of the island is partly covered by scoria and ash. The apparently disturbed nature of the terrain and the abundance of scoriaceous material at the surface seem to point to the existence of a recently active parasitic centre. Scoriaceous material, possibly of recent origin, also lay on the ice above the south coast in 1962.

Kemp and Nelson (1931, p. 179) considered that the basin of Douglas Strait "was once a volcanic crater" and "It is probable that by its eruption it originally formed one large island, and that of this island, Cook and Thule are the only portions now remaining".

There is no doubt that this basin exists but there is considerable doubt as to the role which it played in the development of Cook and Thule Islands. The general form of Thule Island with its highest and steepest side overlooking Douglas Strait could be interpreted as the consequence of eruptions from a source within the basin. Unfortunately it was not possible to establish the dip of the strata along this eastern coast. It is perhaps a little surprising that this, the most severely eroded part of Thule Island, is that which faces the calmest water; it would seem to suggest that some factor other than marine erosion has been involved.

On the other hand, there is good evidence that parts, at least, of both Cook and Thule Islands have been constructed around their own volcanic centres located on the present islands. Although the basin may well be a volcanic centre, there is as yet insufficient evidence that this centre has contributed a significant volume of material to the building of Cook and Thule Islands. A possible alternative is that the basin is a subsidence feature which should properly be regarded as a caldera.

3. *Vegetation and fauna*

The Hewison Point area, which was studied for several hours in both 1962 and 1964, is extremely barren of vegetation. Crustose lichens cover perhaps 10 per cent of rock surfaces away from sea spray, and some areas of muddy ground support *Prasiola* patches, but no bryophytes of any kind have been collected and most of the surface of the platform is of bare earth. Mites and Collembola occur (the first being taken by a party from *Discovery II* in 1930) but only the former in abundance.

Hewison Point is the site of large penguin colonies. As elsewhere in the islands, chinstrap penguins (*Pygoscelis antarctica*) are commonest, at least during the March moulting period. Gentoo penguins (*Pygoscelis papua*) and macaroni penguins (*Eudyptes chrysolophus*) have also been found in lesser numbers on the point on several visits, and Adélie penguins (*Pygoscelis adeliae*) may be present during their breeding season. The main group of gentoos, about 100 strong, occupies a site on the north side of the headland near the Argentine refuge "Teniente Esquivel". Brown skuas and fledged young were seen at Hewison Point in

1962 as were Dominican gulls and their chicks in both years. Wilson's petrels (*Oceanites oceanicus*) were hawking over the cinder slopes above the point in a manner suggesting proximity to a nest burrow.

Hewison Point, in 1962 and 1964, was occupied by a number of fur seal. About 250 were estimated in 1962 and 202 occurred in 1964. Only male animals were seen and it seems certain that the point is not a breeding area. Two Weddell seal (*Leptonychotes weddelli*) were also present in 1964, while a few elephant seal (*Mirounga leonina*) were noted in 1962.

Elsewhere on Thule Island, smaller chinstrap penguin colonies occur on Beach Point and perhaps at Herd Point. A flight around the island revealed colonies of cape pigeon (*Daption capensis*) at Herd Point, Cape Flannery, a rocky outcrop between these two points, and extensively along the rocky northern coast. In contrast, no fulmars (*Fulmarus glacialoides*) were seen nesting anywhere on Thule Island despite their abundance on nearby Cook Island.

At Beach Point seven male fur seal were found in 1964, and about 50 elephant seal were hauled out and moulting. Six Weddell seal were nearby. The two latter species and a leopard seal (*Hydrurga leptonyx*) were seen ashore in this same area by a party from *Discovery II* in March 1930 (Kemp and Nelson, 1931).

V. DISCUSSION

A. Geology: the Island Arc of the South Sandwich Islands

The South Sandwich Islands constitute a relatively small island arc extending over a distance of about 386 km. which compares with 544 km. for the Lesser Antilles, 688 km. for the Mariana Islands, 1,024 km. for the Kurile Islands and 1,920 km. for the Aleutians. The fact that in 1962 a submarine eruption occurred about 56 km. north-west of Zavodovski Island suggests that the South Sandwich Islands arc may not yet have attained its maximum extent (Gass and others, 1963).

As in most other island arcs, there is a deep-sea trench on the convex side of the arcuate chain of the South Sandwich Islands. The distance from the axis of the islands to that of the South Sandwich Islands trench is about 128 km. which compares with a distance of about 160 km. in the case of the Kurile arc, 192 km. in the Mariana Islands and 208 km. in the Lesser Antilles. Relatively few soundings have been made in the South Sandwich Islands trench but depths of over 7,000 m. have been found; the Puerto Rico trench reaches depths of more than 9,000 m. and the Mariana trench reaches nearly 11,000 m.

Most island arcs, e.g. Indonesia and the Lesser Antilles, are composite structures formed by a number of parallel or converging submarine ridges and island chains. The South Sandwich Islands arc, however, appears to have an exceptionally simple structure; ten of the 11 main islands lie on a single arc. Leskov Island is anomalously situated about 56 km. west of the arcuate axis but there is no evidence that it lies on a separate parallel ridge; it appears to rise from a submarine bank which links with Zavodovski and Visokoi Islands.

Between the islands of the South Sandwich Islands group the water usually reaches a depth of about 2,300 m., with a maximum of 2,818 m. occurring between Saunders and Montagu Islands. The sea tends to be appreciably shallower than this between the islands of the Lesser Antilles. Although most of the South Sandwich Islands are quite distinct from their neighbours, there are two instances where islands are closely spaced and separated only by shallow water. First, between Candlemas and Vindication Islands, which are only about 3·2 km. apart, the water of Nelson Strait is only about 24 m. deep. Secondly, Bellingshausen, Cook and Thule Islands, which together form the Southern Thule group, apparently rise from an east–west trending ridge which lies across the axis of the arc; a seamount situated about 3·2 km. south-east of Bellingshausen Island reaches to within 35 m. of the surface and also appears to rise from this same ridge. Between Bellingshausen and Cook Islands, the maximum depth of water is only about 55 m. However, Cook and Thule Islands are linked by shallow submarine banks to the north and south of Douglas Strait, itself a deep basin reaching to 748 m. The basin is possibly a volcanic structure resulting from caldera subsidence.

Protector Shoal is a seamount at the northern end of the South Sandwich islands, 56 km. north-west of Zavodovski Island. Reaching to within 27 m. of the surface, it is a broad gently sloping cone, the sides of which have a gradient of only about 10° in the lower part. Towards its summit there is an appreciable steepening of the gradient, suggesting that a smaller cone may have been superimposed on the main feature. This small summit cone may well have developed in 1962 as pumice dredged from it proved to be identical to the material discharged at the surface in the 1962 eruption at this site (Gass and others, 1963). A topographic profile from north-north-east to south-south-west across Protector Shoal reveals rather gentle slopes to the north in comparison with more irregular, often steeper, slopes on the southern side. A small hump situated about 2·4 km. south of the highest point may be another eruptive conelet.

The South Sandwich Islands are more closely spaced, smaller in area and generally have a lower terrain than their counterparts in other island arcs. The average distance between islands in the South Sandwich Islands group (excluding the short distances between members of the Candlemas and Southern Thule groups) is about 42 km., which compares with 54 km. for the Lesser Antilles, 64 km. for the Mariana Islands, but only 32 km. for the Kurile Islands. The islands of the South Sandwich Islands group are considerably smaller than those found in most other arcs. For instance, the largest of the South Sandwich Islands group, Montagu Island, has an area of only about 102 $km.^2$ compared with 742 $km.^2$ for Dominica in the West Indies and 543 $km.^2$ for Guam in the Mariana Islands. Several individual West Indian islands exceed the total area of the South Sandwich Islands. In both the South Sandwich Islands and the Lesser Antilles, the larger islands are situated in the central and most easterly parts of the arc; however, in the Mariana Islands, the largest island, Guam, is at the southern end of the group, and in the Kurile Islands the larger islands are at each end of the chain.

Volcanic or fumarolic activity has occurred in historic times on eight of the 11 main islands of both the South Sandwich Islands group and the Lesser Antilles. In the Lesser Antilles, the inactive islands (Saba, St. Eustatius and Grenada) are located at either end of the chain. In contrast, the apparently inactive members of the South Sandwich Islands group (Cook, Montagu and Vindication Islands) are fairly regularly distributed along the arc.

The types of volcanicity prevalent in the two island arcs of the Atlantic Ocean are quite different. The characteristic activity of the West Indies is highly explosive, often involving the discharge of pyroclast flows or *nuées ardentes*, as for example in the 1902 eruptions of Mont Pelée in Martinique and Soufriere Volcano of St. Vincent. This type of activity has not been witnessed in the South Sandwich Islands nor have pyroclast flow deposits been recognized on any of these islands, where the dominant activity appears to have been effusive with associated mild eruptions of basaltic cinders and scoria. The contrast in types of activity is reflected in a difference in landforms; although steep-sided central cones constitute the primary volcanoes in the Lesser Antilles and the South Sandwich Islands, the principal secondary centres of the former are volcanic domes and of the latter parasitic cones.

In contrast with most other island-arc provinces, basalts and basaltic andesites greatly predominate over other rock types in the South Sandwich Islands. Two-pyroxene andesites, which, for instance, are by far the most abundant rock types of the Lesser Antilles, are rare in the South Sandwich Islands group except on Leskov Island. Dacites are uncommon in the South Sandwich Islands and, when they do occur as on Candlemas and Cook Islands, they are dark aphyric rocks in contrast to the porphyritic dacites of the West Indies or the Mariana Islands arcs. The only example of rhyolite is the pumice emitted during the 1962 submarine eruption from Protector Shoal; the paucity of material of this composition is, however, not unusual for an island-arc environment.

Most of the features which are regarded as characteristic of island arcs have been recognized in the South Sandwich Islands and in many respects this arc compares closely with that of the Lesser Antilles and the circum-Pacific arcs. There are differences in scale and in the extent to which certain features are developed. The more important distinguishing features of the South Sandwich Islands arc are the predominance of basaltic lavas, the paucity of two-pyroxene andesites and dacites, and the apparent absence of pyroclast flow deposits.

The simple arcuate distribution of the islands, their small size and the obvious youthfulness of many of them, the presence of deep water between islands or island groups, and the dominantly basaltic nature of the lavas all tend to suggest that the South Sandwich Islands arc is in a relatively early stage of development. Perhaps in time it may evolve into an arc which bears an even closer resemblance to that of the present Lesser Antilles where andesitic lavas prevail and volcanicity is generally more explosive.

B. Biology

1. *Vertebrate fauna*

Previous visits by biologists to the South Sandwich Islands (Kemp and Nelson, 1931; Holdgate, 1963) and the present study have all been made in March, after the breeding season of most bird species is over. Thus there is less information about the breeding avifauna than for any other major Antarctic archipelago. The fur seals known to breed in the South Sandwich Islands have also only been seen towards the end of summer but, since pups of the year are unlikely to travel far, their presence on some islands may be taken as proof of breeding in those localities.

Table II summarizes what is known about the bird fauna of the island arc. There is good evidence that four species of penguin—Adélie, gentoo, chinstrap and macaroni—breed in the archipelago, and of these the chinstrap is far and away the most numerous, with colonies in the tens or hundreds of thousands and a total population that must be counted in millions. The macaroni is the second most abundant species; the gentoo probably a little less frequent. The main doubt hangs over the breeding strength of the Adélie penguin, which has not positively been confirmed in the southern islands of the chain yet might be expected to be numerous there, in the coldest conditions of the archipelago. The records of king penguins by Kemp and Nelson (1931) and by earlier visitors from the whaling period are more doubtful; it seems likely that stray individuals probably from South Georgia do visit the group, and especially the northern islands, but it is highly unlikely that they breed there.

Table II

BIRDS RECORDED IN THE SOUTH SANDWICH ISLANDS

Species	*Definite or probable breeding species*	*Recorded on or over land*	*Recorded at sea only*
Aptenodytes patagonicus		1, 6	
Pygoscelis adeliae	1, 4, 6, 7, 9		
P. antarctica	1, 3, 4, 5, 6, 7, 8, 9, 11		
P. papua	3, 4, 6, 11	1	
Eudyptes chrysolophus	1, 3, 4, 5, 6, 7, 8, 11		
Macronectes giganteus	1, 4	3, 6, 7, 9	
Catharacta skua lonnbergi	1, 3, 4, 5, 6, 8, 9, 11	2, 7	
Daption capensis	2, 3, 4, 5, 6, 7, 10, 11	9	
Fulmarus glacialoides	2, 3, 4, 5, 7, 8, 10	9	
Pachyptila desolata	2, 9		
Pagodroma nivea	2, 5, 7, 9		
Oceanites oceanicus	2, 4, 5, 6, 9, 11	3	
Phalacrocorax atriceps	7, 8	4	
Larus dominicanus	5, 6, 9, 11		
Sterna vittata	6		
Procellaria aequinoctialis			6, 8
Phoebetria palpebrata			1
Thalassoica antarctica			7

Key to records

1. Zavodovski Island.
2. Leskov Island.
3. Visokoi Island.
4. Candlemas Island.
5. Vindication Island.
6. Saunders Island.
7. Montagu Island.
8. Bristol Island (including Freezland Rock).
9. Bellingshausen Island.
10. Cook Island.
11. Thule Island.

The petrel fauna is much as might be expected by analogy with other maritime Antarctic localities. The abundance of cape pigeons and fulmars, and the lesser numbers of snow petrels and Wilson's petrel, is comparable with the situation in the South Orkney Islands. The presence of giant petrels, shags, Dominican gulls and terns is equally characteristic. It seems extremely unlikely that the light-mantled sooty albatross breeds in the South Sandwich Islands group as suggested, for example, by Murphy (1936). All the records point to the island arc as a whole having an avifauna typical of the maritime Antarctic zone, and closely similar to that in the South Orkney and South Shetland Islands, and Palmer Archipelago. One difference that does demand comment is the lack of records of sheathbills (*Chionis alba*), which are plentiful in these other island groups. It seems unlikely that these conspicuous birds would have been missed, and their absence may therefore be a genuine one. On the other hand, some species may have been missed because they are not very conspicuous; for example, it may well prove on further examination that the black-bellied storm petrel (*Fregetta tropica*) is a member of the South Sandwich Islands avifauna.

There is insufficient information to permit generalization about regional differences in the bird fauna within the island group. On the whole, the records indicate a surprising level of uniformity. Thus dove prions and macaroni penguins, which do not penetrate so deeply into the Antarctic zone as many species, have been recorded at both extremities of the island arc, the former at Leskov and Bellingshausen Islands, and the latter at Zavodovski and Thule Islands. So far, no gradient in the composition of the fauna along the island chain has been demonstrated, although this might emerge once more observations are made in the breeding season. The records do, however, suggest differences between the bird faunas of different islands that may be related to differences in their suitability as habitats. For example, no penguins have been recorded from Leskov Island, almost certainly because it rises everywhere from the sea in sheer cliffs. The islands with large inland penguin colonies, Zavodovski, Candlemas, Vindication, Saunders and Bellingshausen Islands, all have gently sloping ice-free ground rising from easy landing points. The islands with largely ice-covered terrain, like Visokoi, Montagu, Bristol, Cook and Thule Islands, have substantial penguin colonies, but on headlands (most lava platforms) or talus slopes rising above them. Other species, like the almost ubiquitous cape pigeon and silver-grey fulmar, may be more numerous on the more sheer islands with their massive cliffs.

After the elimination of the breeding population of fur seals (*Arctocephalus gazella*), with the recorded taking of over 6,000 skins between 1875 and 1892 (see p. 5), this species was not reported in the South Sandwich Islands again until 1957. Table III records the sightings of *A. gazella* on the different islands

TABLE III

RECORDS OF *Arctocephalus gazella* IN THE SOUTH SANDWICH ISLANDS AFTER 1957

Date	*Island*	*Locality*	*Numbers* (no pups recorded unless indicated)	*Reference*
1957	Zavodovski	East coast	1 adult, perhaps with 1 pup	Ivanov, 1959*a*
1960	Visokoi	Irving Point	400 animals including pups	O'Gorman, 1961
1962	Visokoi	Irving Point*	550 animals including pups	Holdgate, 1963
	Saunders	Harper Point	30–50 animals	Holdgate, 1963
	Bristol	North-west coast*	10 animals	Holdgate, 1963
	Bellingshausen	South-west coast*	25 animals	Holdgate, 1963
	Thule	Hewison Point	250 animals	Holdgate, 1963
1964	Visokoi	Irving Point	35 males, 305 females and juveniles, 538 pups	Vaughan
		Mikhaylov Point	100 animals including pups	Vaughan
		Finger Point	1 immature animal	Vaughan
	Candlemas	Clapmatch Point	41 males, 266 females and yearlings, 294 pups	Vaughan
	Saunders	Sombre Point*	30–40 adults and juveniles	Vaughan
		Harper Point	43 adult or juvenile males	Vaughan
		North-west from Nattriss Point	4 animals	Holdgate
	Bristol	Main island* and Freezland Rock	19 animals, no pups	Vaughan
	Bellingshausen	Hardy Point	7 adult or immature males	Vaughan
	Thule	Hewison Point	202 adult and juvenile males	Vaughan
		Beach Point	7 adult and juvenile males	Vaughan

*Observed only from helicopter.

from this date onwards. In 1964, when R. W. Vaughan searched almost the whole archipelago, only three breeding colonies were found, on two islands. The largest was that at Irving Point, Visokoi Island, discovered in 1960, and there were small colonies at Mikhaylov Point on the same island and at Clapmatch Point on Candlemas Island. Only adults and juvenile males were found at Harper Point on Saunders Island, where Holdgate (1963) reported a breeding group, suggesting that the latter record was erroneous. The areas chosen by fur seals were in many respects similar to the breeding beaches at South Georgia, the preference being for fairly flat rocky platforms with smoother areas of gravel among the rocks. There are no tussock-grass slopes behind the beaches such as are a favourite haunt of juvenile animals on South Georgia; in the South Sandwich Islands these animals were found on snowy slopes immediately behind the beaches, often among moulting penguins. At the time of the 1964 study the breeding season was almost over and there were very few small pups about; many pups had totally lost their black natal fur. A few pups were still suckling and many remained associated with cows, particularly on Candlemas Island. On Visokoi Island, where there were many more pups than cows, many pups had grouped into "pods" and were playing together in the rock pools at the water's edge. The season appeared a little earlier on Visokoi than on Candlemas Island, and the latter colony, which appears more recently established, may be an "overspill" from Visokoi Island.

One of the female fur seals found by R. W. Vaughan on Visokoi Island was almost white. Animals with this distinctive pelage are well known on South Georgia where they make up about 0·19 per cent of the population, and Bonner (1964) suggested that their appearance in other fur seal stocks might indicate derivation from the South Georgia stock. Øritsland (1960) saw a white animal at Mikkelsen Island in the South Orkney Islands group in 1960, and Vaughan (personal communication) recorded a white bull there in 1965, and the observations suggest that both the South Sandwich and South Orkney Islands populations may be descended from that of South Georgia.

Four other species of seal have been recorded in the South Sandwich Islands. Elephant seals (*Mirounga leonina*) were commonest in 1962 and 1964. The greatest concentration in 1964 was on the shelving beach of black sand in Cordelia Bay west from Nattriss Point on Saunders Island, where Holdgate counted 229 individuals. In both 1962 and 1964 there were about 50 animals hauled out near the fur seal colony at Irving Point, Visokoi Island; in 1964 these were mainly 3 and 5 year old males. A similar number was present in 1964 at Beach Point, Thule Island, and lesser numbers on Candlemas Island, Vindication Island, Montagu Island, Freezland Rock, Bristol Island and Bellingshausen Island, and at Hewison Point on Thule Island. By March all the pups of the year would have left the breeding beaches and the elephant seal population ashore consequently consisted mainly of moulting animals. Moulting elephant seals seem to prefer extensive wallows, which are in short supply in the South Sandwich Islands; Vaughan saw the best-developed examples on Candlemas Island where, however, there were few seals. It is known that some of the very large population of elephant seals at South Georgia move away from that island and moult in the South Orkney Islands, and some of the animals seen in the South Sandwich Islands group may also have come from South Georgia. It is, however, very probable that elephant seals breed in the South Sandwich Islands, and there are suitable localities at Beach Point on Thule Island, Irving Point on Visokoi Island, several places on Candlemas Island, and along the southern shores of Cordelia Bay on Saunders Island. Ivanov (1959*a*) reported elephant seals ashore at Zavodovski Island, where they are also likely to breed.

Weddell seals (*Leptonychotes weddelli*) were recorded at Thule, Saunders and Montagu Islands by Kemp and Nelson (1931). In 1964 the species was seen singly or in small groups on six of the islands, the largest congregations being of six individuals hauled out on the south shore of Cordelia Bay, Saunders Island, and at Beach Point on Thule Island. Three were seen at Visokoi Island and single animals on Candlemas, Bellingshausen and Montagu Islands. It is likely that some Weddell seals breed in the South Sandwich Islands group. Leopard seals (*Hydrurga leptonyx*) were seen more commonly, and Kemp and Nelson (1931) found this to be the most abundant species in 1930, especially in the sea off large penguin colonies; they also saw several ashore at Beach Point on Thule Island. In 1964, leopard seals were seen ashore on Candlemas and Saunders Islands, and at sea off Visokoi, Vindication and Bellingshausen Islands. The species is likely to breed in the area, especially in years when pack ice is extensive. Finally, in 1964, one crabeater seal (*Lobodon carcinophagus*) was seen ashore on Montagu Island and another in the sea off Bellingshausen Island. This seal is a species of the pack ice, and its presence (and breeding) around the South Sandwich Islands is likely to be largely governed by the movements of the ice.

2. *Invertebrate fauna*

Most of the obvious macro-habitats on the islands were examined for arthropods (collections being made by aspirator or heat extraction) and some moss samples from Candlemas Island were subjected to a "wet" extraction technique in order to examine the mesofauna inhabiting the moss water (Tilbrook, 1967*a*, *b*).

Eleven species of free-living Acari and two Collembola were found in sufficient frequency or numbers to suggest that they are established components of the fauna (Table IV). The collembolan fauna is particularly impoverished compared with other maritime Antarctic localities (Tilbrook, 1967*a*) and of the Acari one species and two sub-species are endemic. The composition of this fauna indicates its origins. Five of the Acari were found at South Georgia but not from other Scotia arc or Antarctic Peninsula localities. This suggests that the dominant westerly winds in these latitudes may be responsible for the dispersal of these organisms. That all five species are heavily sclerotized, and so better able to withstand desiccation, would also support this hypothesis. Three of the species, however, were only found associated with fumaroles, so it seems that ecological as well as distributional factors have influenced the arthropod fauna of these islands.

The "black" (the actual pigment is deep magenta) collembolan *Cryptopygus antarcticus* Willem was the most widespread arthropod throughout the whole island group, occurring in nearly all terrestrial habitats. This species has a circum-polar distribution and is probably the commonest in the maritime Antarctic

TABLE IV

SPECIES OF ACARI AND COLLEMBOLA COLLECTED FROM THE SOUTH SANDWICH ISLANDS, ON WHICH ISLANDS THEY WERE FOUND AND THEIR FREQUENCY OF OCCURRENCE IN DIFFERENT BROAD HABITAT TYPES (FIGURES ARE THE PERCENTAGE OF THE TOTAL NUMBERS OF SAMPLES IN WHICH EACH SPECIES OCCURRED)

Species	*Island*							*Habitat type*			
	Leskov	Visokoi	Candlemas	Vindication	Saunders	Bristol	Bellingshausen	Around fumaroles	Vegetation away from fumaroles	Rocks, debris, encrusting lichens, etc.	Bird colonies and nests
ACARI											
Mesostigmata											
Gamasellus rykei (Hunter)		+	+	+				0	18	21	46
Ayersacarus tilbrooki Hunter	+	+	+	+	+		+	38	47	21	54
Cryptostigmata											
Oppia crozetensis (Richters)	+		+					8	0	0	0
Globoppia intermedia Hammer			+					5	0	0	0
Alaskozetes antarcticus intermedius Wallwork	+	+	+	+	+	+	+	22	53	79	69
Halozetes belgicae longiseta Wallwork	+	+	+	+			+	19	41	7	15
Edwardzetes elongatus Wallwork	+		+				+	5	0	0	0
Astigmata											
Neocalvolia antarctica (Hughes et Tilbrook)	+		+					0	0	14	0
Prostigmata											
Eupodes minutus (Strandtmann)	+	+	+	+	+	+	+	16	82	50	8
Pygmephorus sp.			+					0	12	0	31
Nanorchestes antarcticus Strandtmann	+	+	+	+	+	+	+	24	82	86	54
COLLEMBOLA											
Cryptopygus antarcticus Willem	+	+	+	+	+		+	87	100	71	100
Archisotoma brucei (Carpenter)		+	+		+		+	5	6	14	0
Number of species	9	8	13	7	6	3	8	10	9	9	8
Number of samples taken	13	5	44	6	6	1	6	37	17	14	13

(Tilbrook, 1970). With a maximum length of approximately 1,400 μm., it is one of the largest invertebrates in the South Sandwich Islands, although here and at Bouvetøya and South Georgia it does not reach the same adult size as at other localities farther south. The highest densities of this species were found in areas not subjected to heat, about 990×10^3/m.^{2} for example, inhabiting a mixed bryophyte mat on Leskov Island. This particular sample was exceptionally rich, yielding high numbers of two small prostigmate Acari, *Nanorchestes antarcticus* Strandtmann (53×10^3/m.^{2}) and *Eupodes minutus* (Strandtmann) (26×10^3/m.^{2}) as well as some immature Cryptostigmata. A comparison of arthropod densities in two common mosses both around and away from fumaroles, however, suggested that *C. antarcticus* preferred *Pohlia* sp. in the heated areas but *Polytrichum* sp. away from heat (Tilbrook, 1967*a*, *b*). The frequency and habitat preference of the arthropod species have been given by Tilbrook (1967*b*).

Nematodes, tardigrades and rotifers were also found in samples taken from Candlemas Island, though these were not identified to species level. Total nematode numbers were very high in some sites with $5 \cdot 1 \times 10^6$/m.^{2} found in *Pohlia* sp. moss around a fumarole.

It would seem from this brief study of some of the groups, therefore, that the South Sandwich Islands terrestrial invertebrate fauna consists of relatively few species from the groups commonly represented in other high southern latitudes. The composition of the fauna closely resembles that of other maritime Antarctic localities and, in common with these and other extreme environments, many of the species are found in very high numbers. There is also a small South Georgian element in the arthropod fauna.

3. *The biological characteristics of the South Sandwich Islands*

The terrestrial biology of the South Sandwich Islands reflects three major features: their volcanic origin and structure, their remoteness and their location within the maritime Antarctic zone. The first of these accounts for the lack of standing fresh water almost throughout the archipelago (there are a few small ponds on one or two islands but no substantial lakes and no likelihood of any significant fresh-water flora or fauna). It also results in the soils being in many areas highly permeable so that there is little surface water of any kind, and moisture released from melting snow rapidly sinks into the substratum. As a corollary, many areas are covered in loose volcanic debris and there is a good deal of wind-blown dust. Finally, the volcanic nature of the island group is reflected in their most spectacular biological feature, namely the existence of fumaroles which supply constant moisture and warmth, and provide genuine oases in the cold desert. These features have not been described elsewhere in the Antarctic regions and are clearly a rarity in the polar regions of both hemispheres. They thus give the group a distinctiveness and an interest which would otherwise be lacking.

The remoteness of the island group together with its relative youth probably helps to account for the general impoverishment of the biota. The vegetation of cooled ground is species-poor compared with that in the South Orkney or South Shetland Islands which are climatically similar but of greater antiquity. The terrestrial invertebrate fauna is also relatively impoverished. Only the sea-bird and seal fauna is more or less equivalent in its diversity and abundance to that found in parts of the maritime Antarctic zone farther to the west and south. While the inhospitable nature of much of the terrestrial habitat may account for some of the botanical and invertebrate zoological poverty, it seems likely that biogeographical factors have also had some influence.

Despite this, the South Sandwich Islands can clearly be placed within the maritime Antarctic zone on climatological and biological grounds. They support vegetation types which, except for the unique complexes around fumaroles, fall clearly within the scheme developed by Gimingham and Smith (1970) for the areas around the Antarctic Peninsula and the South Shetland and South Orkney Islands groups. The classification and relationships of the vegetation have been reviewed by Longton and Holdgate (1979). The invertebrate and vertebrate fauna are likewise typical of the maritime Antarctic zone.

While a reasonably complete description of the land biota of the island group is now available, no significant observations of the shallow-water marine fauna have yet been made. It can be predicated that this will resemble rather closely that of other maritime Antarctic localities, and especially the South Orkney Islands. However, the lack of sheltered coastal areas and the exposure of the islands to heavy seas and storms suggests that this shallow-water fauna will be relatively impoverished. This impoverishment may be accentuated by the fact that the islands are all fairly steep, and there is a shortage of shelving reefs below the reach of the tides and of surface ice scour.

Apart from the reduction or elimination of the small population of breeding fur seals in the nineteenth century, the South Sandwich Islands have suffered little disturbance by Man. Their vegetation is undoubtedly potentially vulnerable to human interference and the mats around the fumaroles at Bellingshausen and Candlemas Islands merit careful safeguarding. There is a strong case for conferring on parts of these islands the same degree of protection that is provided for Specially Protected Areas under the Agreed Measures for the Conservation of Flora and Fauna in the Antarctic but, since the island group lies outside the area covered by the Antarctic Treaty, this safeguarding would need special negotiation. Scheduling under the Agreed Measures could also safeguard the increasing fur seal population, which may be expected to number some tens of thousands strong by the end of the century.

VI. ACKNOWLEDGEMENTS

WE are most grateful to Capt. M. S. Ollivant, M.B.E., D.S.C., R.N., who commanded H.M.S. *Protector* at the time of the field survey, and all those aboard that ship who helped our work. Particular thanks are due to the First Lieutenant, Lt-Cdr A. Crosse, R.N., and the pilots of the ship's flight, Lt J. Leeson, R.N. and Lt A. Mathias, R.N., who landed us in various improbable places under difficult conditions. All members of the scientific party contributed to the observations described in this general report, and we are grateful especially to Dr. P. J. Tilbrook and R. W. Vaughan, who have helped us to compile the biological records. Finally, it is a pleasure to thank Sir Vivian Fuchs, F.R.S., then Director of the British Antarctic Survey, and Rear Admiral Sir Edmund Irving, then Hydrographer of the Navy, for their encouragement.

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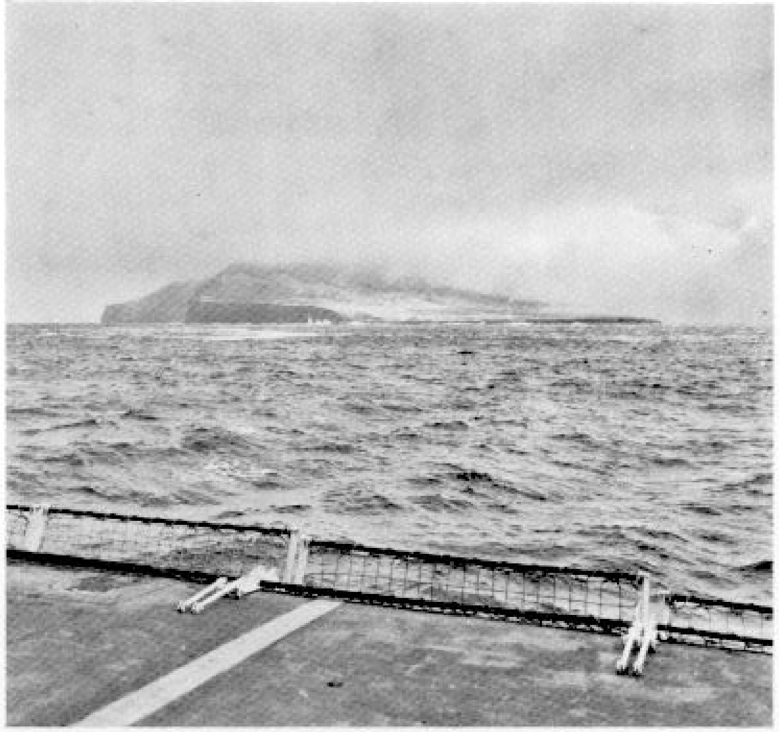
PLATE I

Zavodovski Island

a. Zavodovski Island from the south. Stench Point is the prominent bluff on the left, Noxious Bluff the nearer dark cliff, while on the right low lava flows run out to Fume Point. The cloud base on Mount Curry is at about 300 m. The pale streak on the sea in the middle distance is pumice from a submarine eruption.

b. Cliffs of banded pyroclastic rocks above basalt flows near Stench Point, Zavodovski Island. A penguin colony occupies the flanks of Mount Curry above the cliff.

c. Panorama of the northern side of Zavodovski Island, with Acrid and Stench Points on the right and debris-covered lowland running out towards Pacific Point in the foreground. The cloud base on Mount Curry is at about 300 m.
(All photographs taken in March 1962. Photographs reproduced by courtesy of the Admiralty.)



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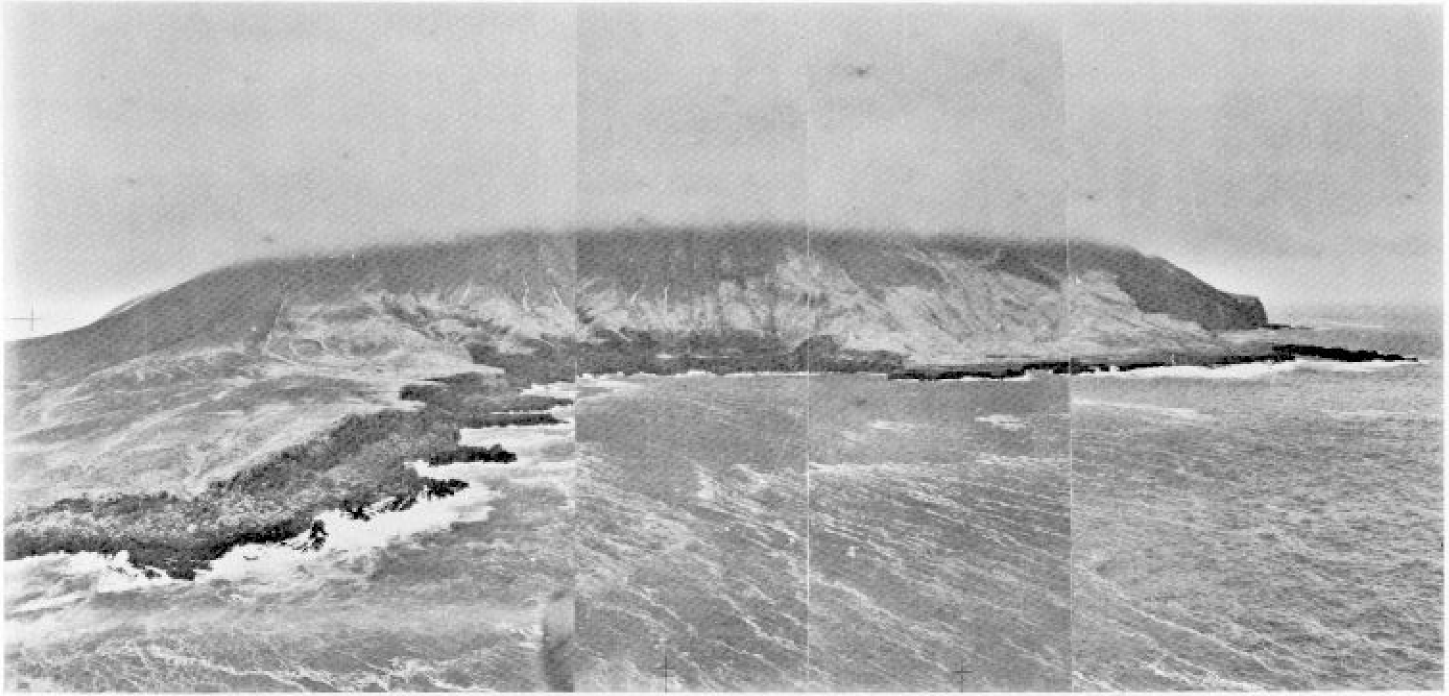

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PLATE I

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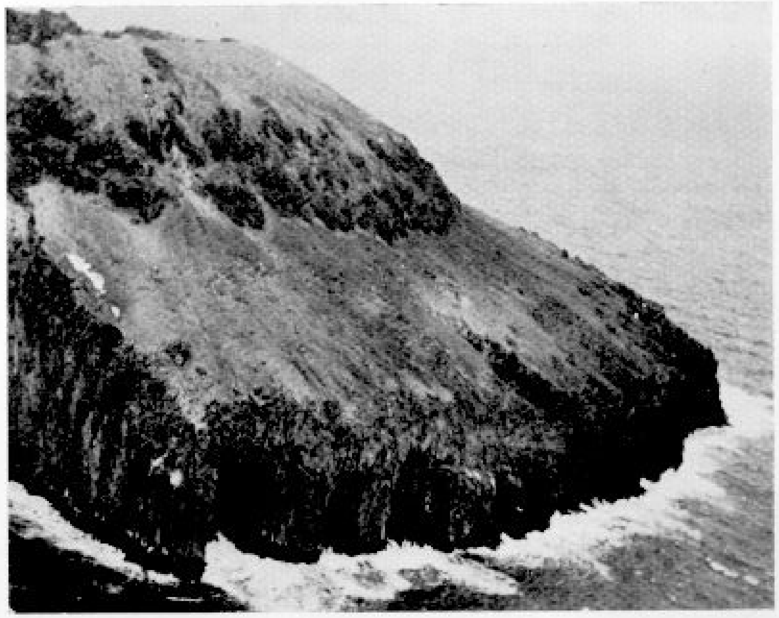

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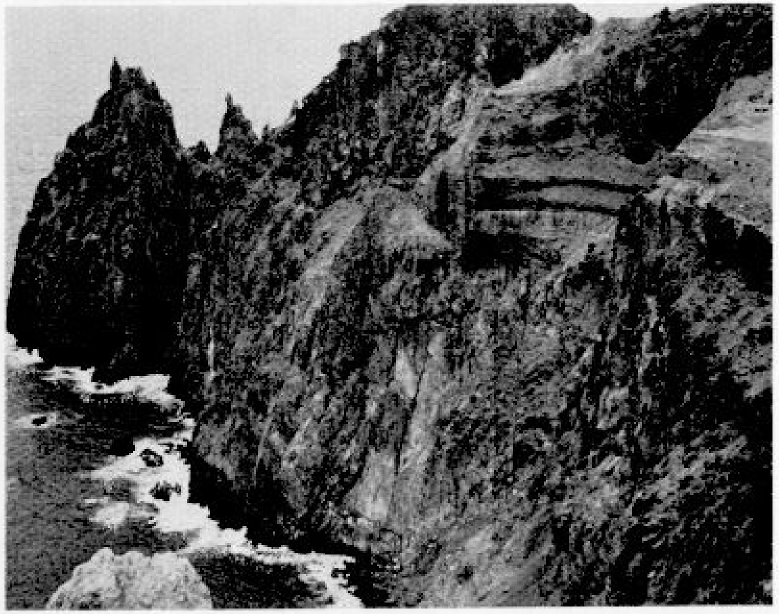

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PLATE II

PLATE II

Leskov Island

a. From the north-east looking into Crater Bay. Bowsprit Point is the nearest part of the island and Rudder Point is the prominent mass on the left. The active fumaroles are distributed along the crest of the island above the line of dark cliff. (Photograph reproduced by courtesy of the Admiralty.)

b. From the south. Rudder Point is on the right and the regular outer slopes of the cone extend towards the left. (Photograph reproduced by courtesy of the Admiralty.)

c. The north-west corner of the island, showing the two thick series of lava flows which form the dominant feature of the west coast.

d. The east coast, above Crater Bay, looking towards Rudder Point. Thick lava flows, form most of the sequence but regularly bedded pyroclastic materials are conspicuous high up on the right.

PLATE III

Visokoi Island

a. Finger Point, the northernmost extremity of the island. A young lava flow forms the point and there is fumarolic activity on the slopes above. The white streaks on the foreground sea are pumice from an undersea eruption.

b. From the south-east. Wordie Point is the massive headland on the left and Irving Point is the low feature on the right. The cloud base is only just below the summit of Mount Hodson at 1,000 m. The asymmetrical profile of the island is obvious.

c. Looking west from a point just east of Saddle Bluff, which is the dark outcrop above the coast on the right. Another secondary eruptive centre rises above Irving Point on the left, while the dark pointed hill in the right middle distance is Shamrock Hill. The crest of Mount Hodson is partly visible in the distance.

d. Irving Point. About 550 fur seal and several elephant seal are visible on the sandy beach and among the rocks.
(All photographs taken in March 1962. Photographs reproduced by courtesy of the Admiralty.)

a

b

c

d

PLATE III

PLATE IV

Candlemas Island

The northern part of the island, from the north. Lucifer Hill is the prominent scoria cone in the centre, and the source of the series of overlapping lava flows forming Vulcan Point, in the right foreground, the headland beyond Tow Bay and Cauldron Pool, in the right middle distances, and Breakbones Plateau on the left of the cone. Medusa Pool is the conspicuous lagoon beyond Lucifer Hill, with Sarcophagus Point beyond it and Carbon Point in the distance. The snow slopes in the left distance are part of the ice cap that covers most of the southern half of the island. (Photograph reproduced by courtesy of the Admiralty.)

PLATE IV

PLATE V

Candlemas Island

a. The ice-capped southern half of the island seen across Nelson Channel from Vindication Island. Shrove Point, as the southern extremity of the island is on the extreme right. Mount Andromeda and Mount Perseus are the right- and left-hand peaks, and Medusa and Gorgon Pools are the water bodies lying left of the cliffs falling from Mount Perseus. Trousers Rock and Cook Rock are conspicuous in the foreground.

b. Cauldron Pool from the south-west with Lucifer Hill beyond. The pool, which is 200 m long, is isolated from the sea by a broad shingle bar, and the prominent lava cliffs behind the lake are part of an old coastline now cut off by the recent lava flows in the right and left foreground. There are numerous fumaroles on the near slopes of Lucifer Hill. Demon Point is the low headland in the right distance. (Photograph reproduced by courtesy of the Admiralty.)

c. The lowlands between the two halves of Candlemas Island. Part of Sarcophagus Point occupies the foreground with Medusa Pool, Chimaera Flats, Gorgon Pool, Kraken Cove and Demon Point beyond. Breakbones Plateau covers the lava flow on the left, and the cliffs and ice slopes on the right rise to Mount Perseus. (Photograph reproduced by courtesy of the Admiralty.)

d. Northern Candlemas Island from the south. Sarcophagus Point lies in the foreground, dividing Seaserpent Cove from Medusa Pool. Beyond rises Lucifer Hill with its surrounding lava flows. (Photograph reproduced by courtesy of the Admiralty.)

a

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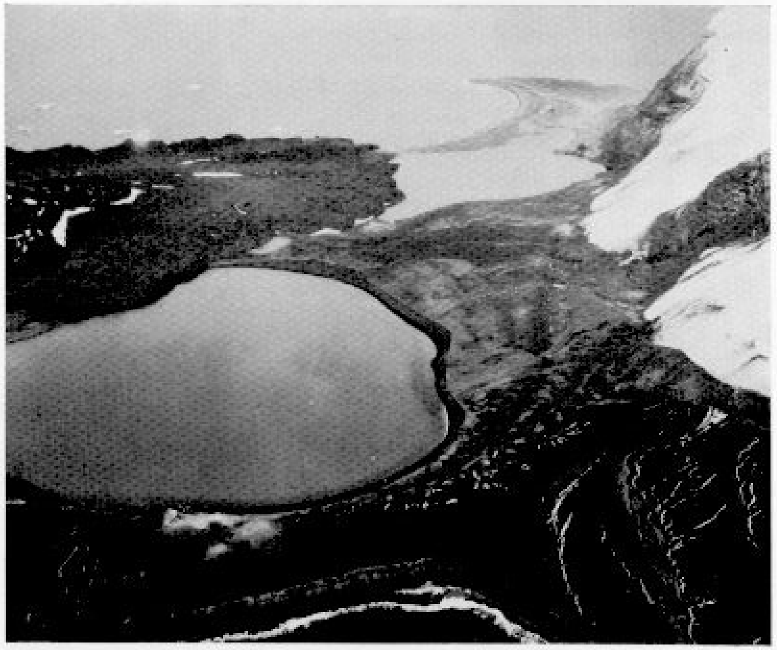

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PLATE V

PLATE VI

Vindication Island

a. From the north-west. Crosscut Point is the jagged headland in the foreground. It forms the northernmost point of the island and from it the pinnacled ridge rises to Splinter Crag. The sheer north-western cliffs of the island are conspicuous beyond, falling almost from the summit of Quadrant Peak with its thin apron of ice. The smooth eastern slopes of Quadrant Peak, in contrast, probably preserve something close in the original profile of the volcano. Buddha Rock is the sea stack on the right.

b. The whole island from the north. Crosscut Point with its offlying islets is the nearest point, Knob Point is the massive bluff at the western extremity of the island on the right, and Braces Point is the low shingle spit, ringed by surf, below the lower cliffs on the left. The island, from this angle, is immediately recognizable as a remnant of a much larger volcanic cone. (Photograph reproduced by courtesy of the Admiralty.)

c. The south-west coast, from a point just off Chinstrap Point. Buddha Rock lies offshore on the left, amid grounded icebergs, and the high cliffs rising from Knob Point to Quadrant Peak limit the view. Splinter Crag is just visible above the even skyline on the right. In the foreground, Pothole Gulch meanders down the gentle south-western slopes. (Photograph reproduced by courtesy of the Admiralty.)

d. From the east. Braces Point runs out of the picture from below the bluff in the right foreground, and on the right the north-west coast extends to Crosscut Point. Streams draining the ice-covered slopes of Quadrant Peak have cut the dendritic gully pattern of Leafvein Gulch to the right of the centre.

a

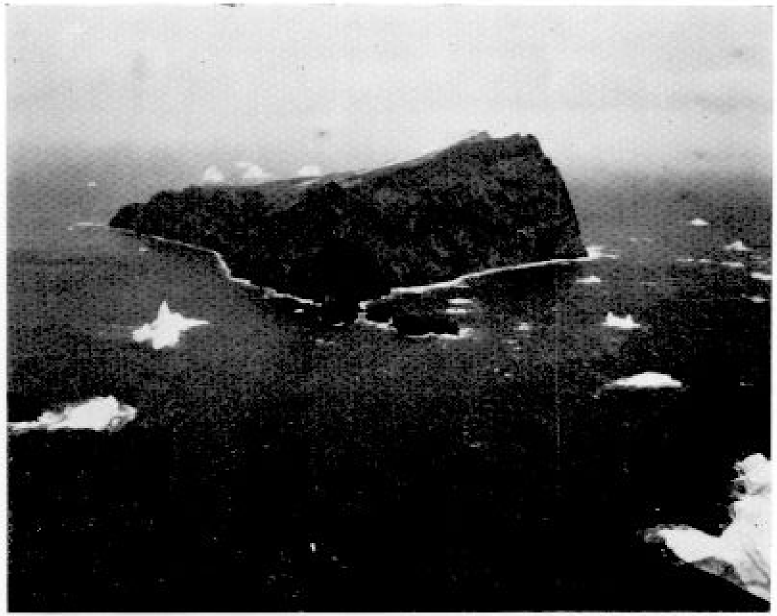

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PLATE VI

PLATE VII

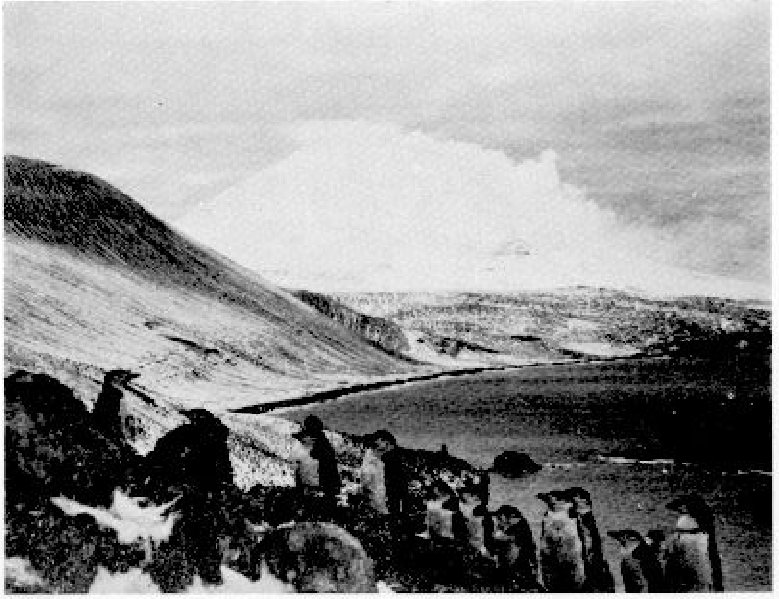
Saunders Island

a. Mount Michael, with its characteristic vapour plume, viewed from above Nattriss Point near the eastern extremity of the island. The gullied scoria slopes of Ashen Hills in the left foreground are brought out by light snow cover; dark scoria also covers the lower slopes of the glacier in the centre and right middle distance, beyond the curving shore of Cordelia Bay.

b. Panoramic view from the north-north-east. Brothers Rocks, off the centre of Cordelia Bay, are virtually in line with Nattriss Point on the left. Turning westward, the snow-free rounded crest of Ashen Hills rises above the ash-covered glacier falling from Mount Michael, which is partly obscured by vapour. The nearest coast is that of Blackstone Plain, visible as a low, broken dark line running from Sombre Point past Yellowstone Crags to beyond Harper Point on the right. (Photograph reproduced by courtesy of the Admiralty.)

c. Yellowstone Crags. These striking pinnacles and mounds of yellow tuff, with many embedded boulders, are the most conspicuous features of the north-east corner of Saunders Island, lying between the lava desert of Blackstone Plain and the ice-clad slopes of Mount Michael.

d. Blackstone Plain forms the northern part of Saunders Island. It is a confused wilderness of recent lava flows with a relatively uniform elevation only about 30–50 m above the sea. Yellowstone Crags are the prominent bluffs in the distance.



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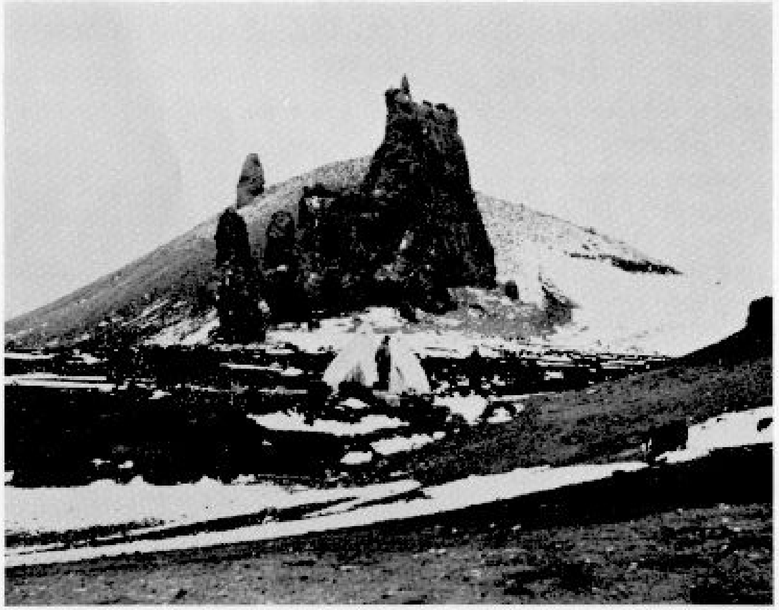

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PLATE VII

PLATE VIII

MONTAGU ISLAND

a. Mount Oceanite, an ice-covered secondary volcanic centre about 1,000 m high, occupies the south-eastern extremity of Montagu Island. In this view from the south, Allen Point is the low cliffed headland on the right.

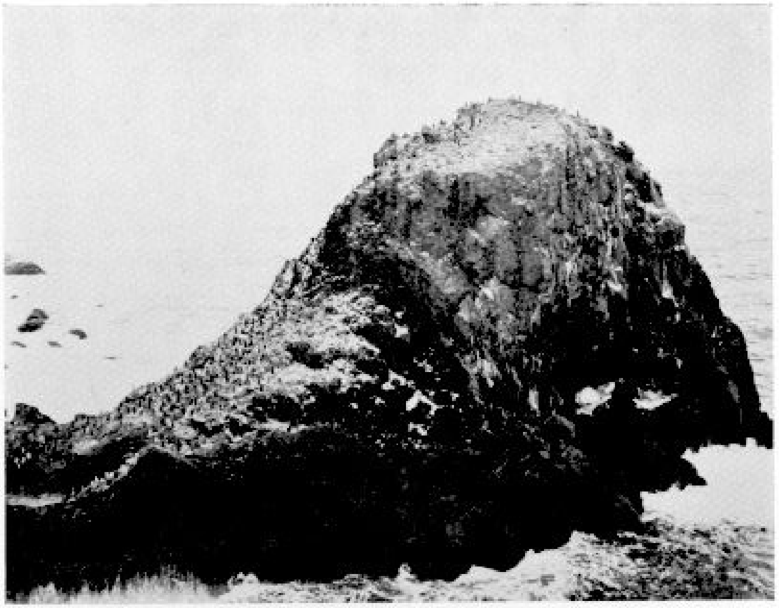
b. Mathias Point, on the east coast of Montagu Island and to the north-east from Mount Oceanite, is composed of oceanite lava overlain by scoria and debris.

BRISTOL ISLAND

c. Bristol Island from the west. Wilson Rock and Grindle Rock are the two prominent islets in the foreground (a helicopter from H.M.S. *Protector* appears nearly in line with the summit of Wilson Rock). Turmoil Point is the prominent cliffed bluff forming the western extremity of Bristol Island, which is largely ice-covered; Fryer Point, the northernmost corner of the island, is at the far left. The narrow line of partly ice-free ground beyond and to the right of Turmoil Point is probably the rim of the recent eruptive centre. (Photograph reproduced by courtesy of the Admiralty.)

d. Freezland Rock from the south-west. This is the highest of the three islets west of Bristol Island, reaching 300 m; it was Cook's first landfall when discovering the South Sandwich Islands. The island is composed of tuffs and agglomerates protected by andesitic dykes. (Photograph reproduced by courtesy of the Admiralty.)

a



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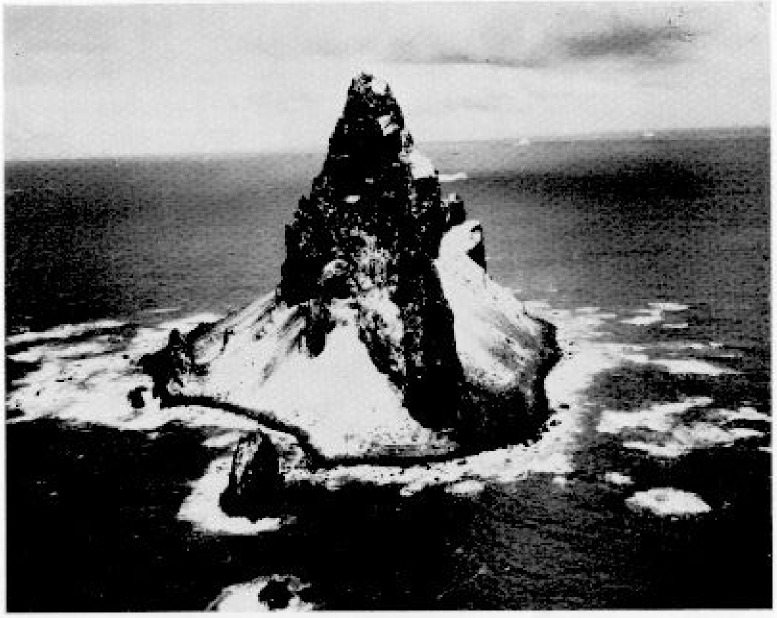

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PLATE VIII

PLATE IX

Bellingshausen Island

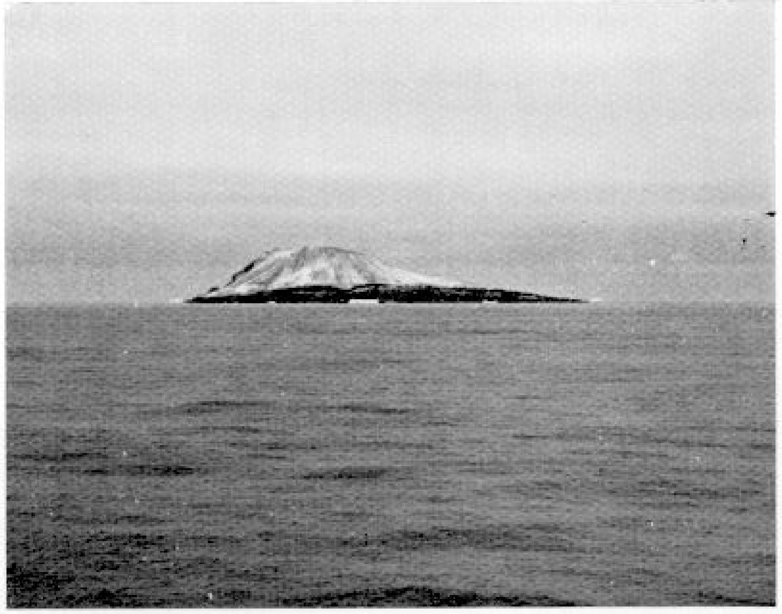
a. From the north-west. From this angle, the simple cone of Basilisk Peak appears almost perfect, its gullied slopes picked out by light snow. Jagged Point, the eastern extremity of the island, is partly visible over the shoulder of Salamander Point, the northernmost headland on the left, while the even cliffs of the north-west coast extend to the low lava reefs of Hardy Point on the right.

b. The crater from the south-west. Basilisk Peak is at the left of the series of sharp crests. In the foreground, the uneven slopes are locally warmed by volcanic heat and a series of fumaroles, emitting steam, lies along the terrace that shows dark across the centre of the slope. The richest areas of vegetation on the island lie around these fumaroles. (Photograph reproduced by courtesy of the Admiralty.)

c. Jagged Point from the outer rim of the crater. The base of the point is formed by lava, which protects the interbedded tuffs exposed in the cliffs above.

d. Basilisk Peak and the western wall of the crater from the north-east. The thick layer of red agglomerate and the series of grey tuffs below it are conspicuous. The ice dome that fills the western half of the crater floor is visible at the lower left, and the south-east corner of Cook Island appears in the distance.

PLATE IX



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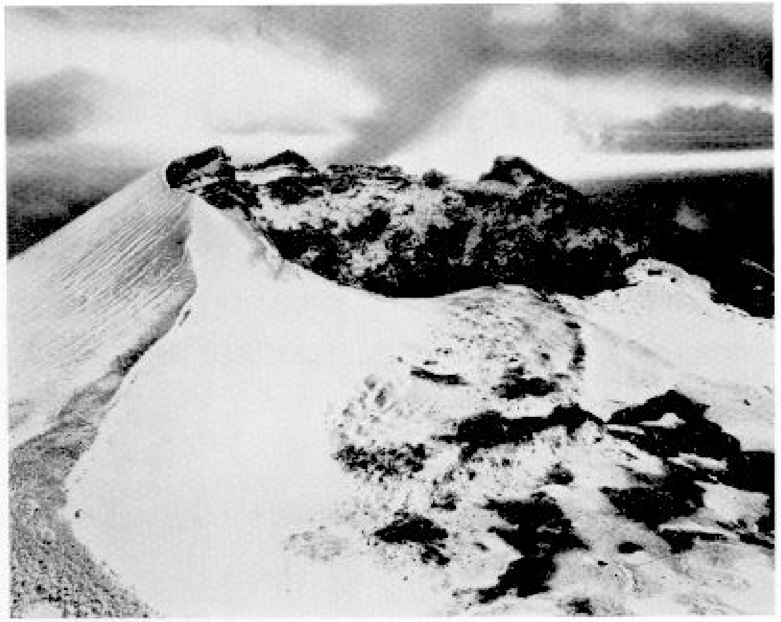

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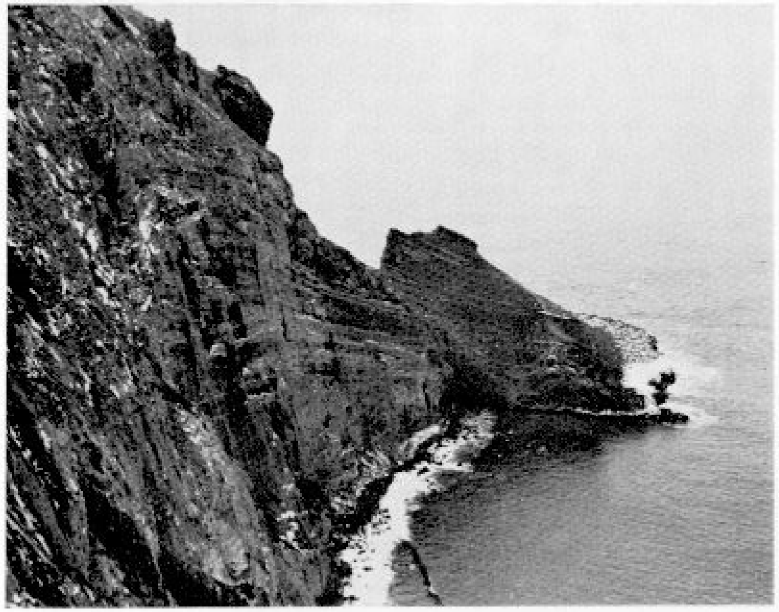

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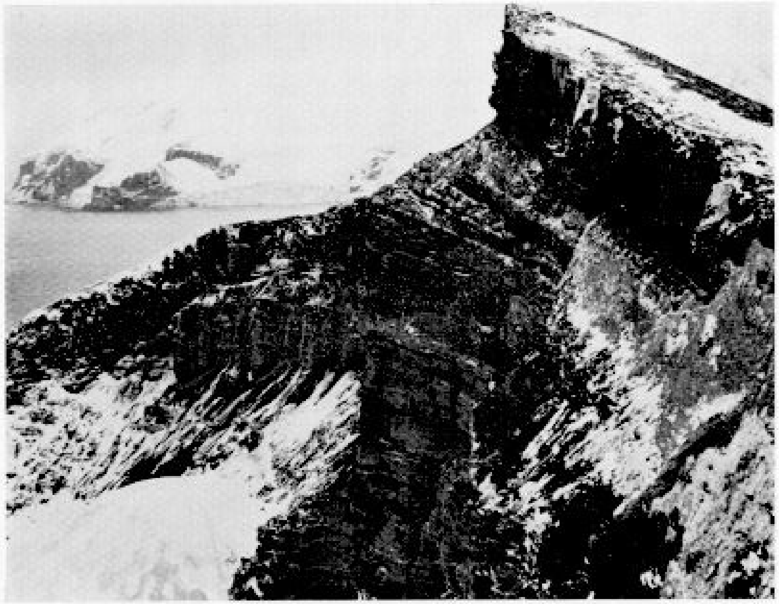

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PLATE X

Cook Island

a. Reef Point at the south-west corner of Cook Island is one of the few areas of lowland on the island; it is composed of a recent dacite lava flow. North of it, the west coast runs in a shallow embayment of ice cliff to Tilbrook Point, on the left, while above the coast the slopes mount steeply to the ice-covered central mountains.

b. Longton Point is the south-eastern extremity of Cook Island. Swell Point is the lesser headland beyond and Bellingshausen Island is visible under cloud to the north-east.

c. The south coast of Cook Island from the south-east. Reef point is the distant headland on the left, Jeffries Point the bluff where ice and rock meet in the centre of the run of coast, and at the extreme right of the photograph is the commencement of the cliff that runs out to Longton Point. Mount Holdgate is the mountain in the right foreground.

d. The south-east corner of Cook Island from the south. Longton Point is at the right and Jeffries Point is on the left. The skyline is made up of the three highest peaks of the island: Mount Harmer (about 1,075 m) on the left, Mount Holdgate (about 945 m) on the right and an unnamed summit between them.
(Photographs reproduced by courtesy of the Admiralty.)

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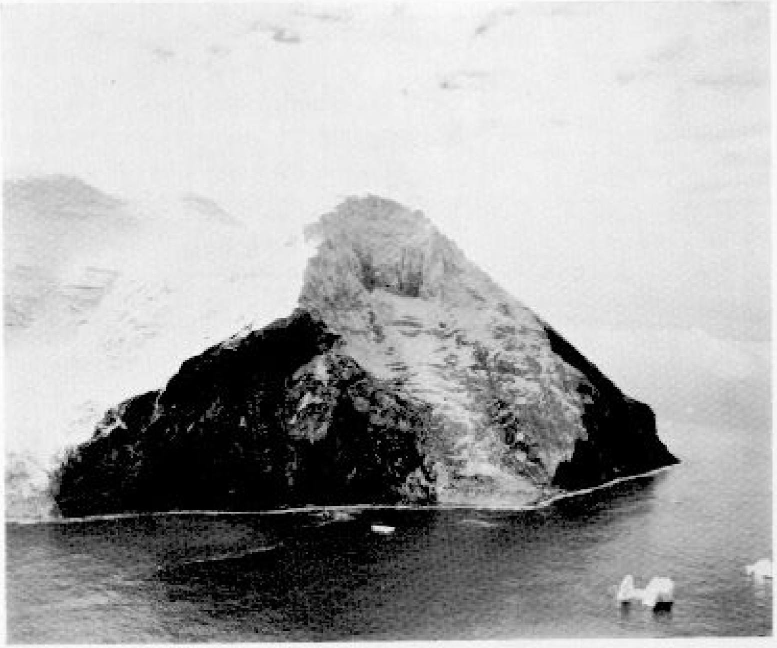

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PLATE X

PLATE XI

Thule Island

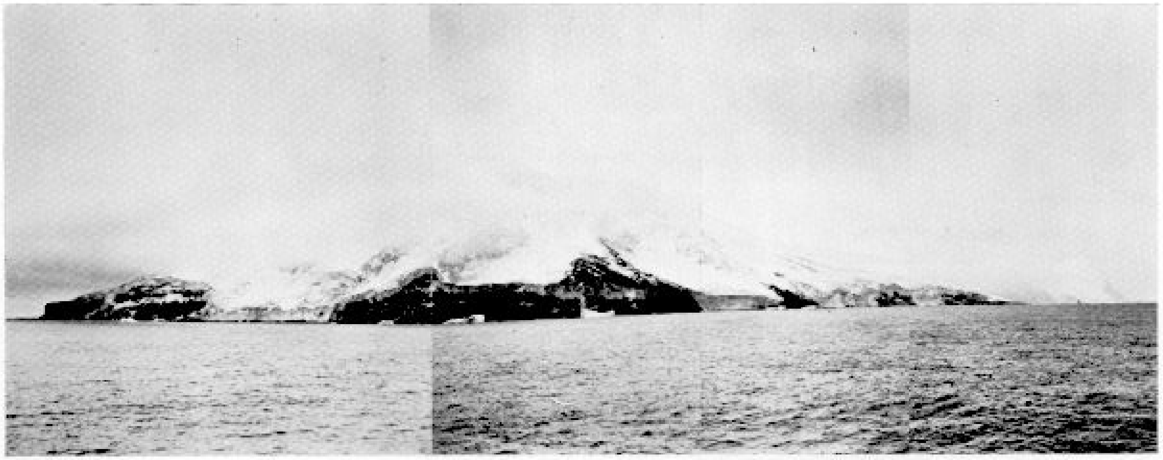
a. Panoramic view of Thule Island from the south-west. Cape Flannery is the conspicuous headland, forming the western extremity of the island, seen on the left, and Herd Point is the low dark point on the right, with Cook Island beyond. Parts of the upper ice-covered cone of Thule Island are clear of cloud in the right of centre of the photograph. (Photograph reproduced by courtesy of the Admiralty.)

b. The western extremity of Thule Island. Cape Flannery is the further headland and Morrell Point is the nearer one. To the left is a section of the high ice and rock cliffs falling from the shoulder of Mount Larsen. (Photograph reproduced by courtesy of the Admiralty.)

c. Beach Point, the north-eastern headland of Thule Island, from the south-east, with part of Douglas Strait in the foreground.

d. Hewison Point, the south-eastern extremity of Thule Island, from the north-west. The headland is a low-lying lava platform. Twitcher Rock, the prominent stack beyond, commemorates one of the personal characteristics of the Earl of Sandwich, who gave his name to the island group.

PLATE XI



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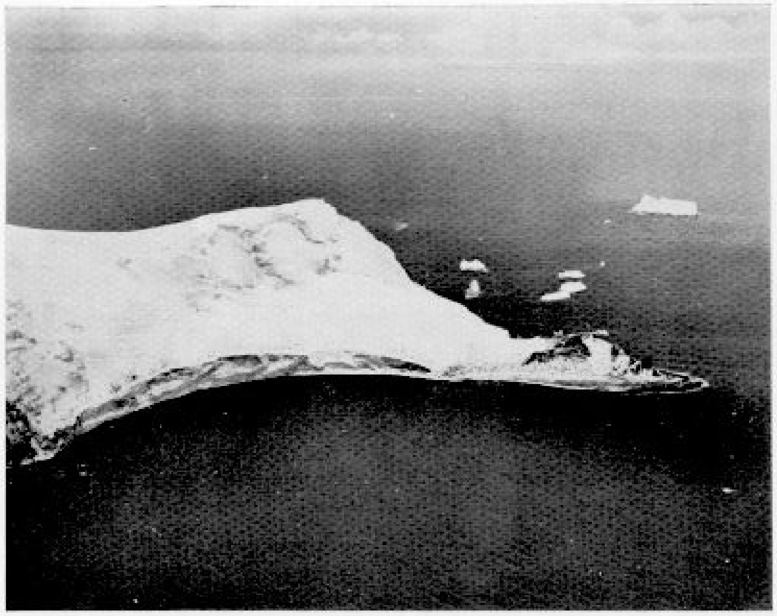

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