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THE STRATIGRAPHY OF PART OF NORTH-EAST GRAHAM LAND AND THE JAMES ROSS ISLAND GROUP

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ABSTRACT

THIS report is concerned principally with the geology of the Mesozoic rocks of north-east Graham Land. These crop out on James Ross Island, but several small areas on Trinity Peninsula, where rocks of Jurassic age occur, are also considered. Andesites are reported from the Jurassic sequence in north-east Graham Land for the first time.

The area over which Cretaceous rocks are known to crop out has been extended by the discovery of large exposures near Rink Point and Rabot Point on James Ross Island, and at Cape Lamb on Vega Island. The latter locality is exceptionally fossiliferous.

A sequence based partly on lithological and partly on palaeontological grounds has been established in the Lower to Middle Campanian (Upper Cretaceous) sediments of James Ross Island. The structure of the beds in the west is affected by movements along the Prince Gustav Channel fault. In the east the structure is deduced only from stratigraphic evidence, and it is hoped that this will be of value in further elucidating the relationships between the ammonite faunas. The earlier lack of stratigraphic data from this area has been commented on by Spath (1953) and Howarth (1958).

The evidence in support of faulting in Prince Gustav Channel is summarized. It is considered that the channel occupies the site of a wide fault zone rather than a single fault.

The basal strata of the James Ross Island Volcanic Group are only examined in so far as they provide information relating to the unconformity between the Cretaceous beds and the overlying volcanic rocks. This is unusual in that it is a highly irregular surface produced by subaerial erosion, but the sediments which cover it are marine in origin and ophiuroid impressions have been discovered in them. Pillow lavas are also found. The geological history is described with reference to a geosynclinal basin which migrated slowly from west to east.

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I. INTRODUCTION

THE area in which the Hope Bay station of the British Antarctic Survey is situated has been known since the end of the nineteenth century when Sir James Clark Ross sailed along the coasts of the outlying islands. Dr. O. Nordenskjöld, leader of the Swedish South Polar Expedition, 1901–03, named the bay which he noted as a suitable landing place and site for establishing a depot of stores in 1901. Geological survey in this area commenced in 1902 when a party of three Swedes, including J. G. Andersson (a geologist), was marooned after the sinking of the *Antarctic* by pack ice. They were responsible for discovering the Mount Flora plant-bearing shales.

Survey had commenced one year earlier in the southern part of the area, where the main party was wintering on Snow Hill Island. This party was also at work during 1902 when they discovered Prince Gustav Channel and Herbert Sound, and successfully circumnavigated James Ross Island by sledge. They were responsible for the first geological descriptions and fossil collections from the Cretaceous and Tertiary rocks of the James Ross Island group.

The area was not re-visited after the evacuation of these parties in 1903 until the first British station was established at Hope Bay in 1945. Since this date extensive geological data have been collected by many sledge parties. Croft (1947), Stoneley (1953) and Standring (1956) investigated parts of the Mesozoic and Tertiary sedimentary successions, and in order to complete this work four major geological journeys were undertaken by the author in 1958 and 1959. Of the two 1958 journeys, the first served as a reconnaissance of Bald Head, Botany Bay and the west coast of James Ross Island. The party of three hauled their own sledge but they were supported and supplied by dog sledge and remained in the field for 69 days during June, July and August. In September and October a further journey was undertaken, this time by dog sledge; this proved considerably more convenient due to the speed with which outcrops could be visited. On this journey plane-table survey on a scale of 1 : 10,000 was carried out south-west of Brandy Bay, and on 1 : 20,000 over the Hidden Lake and Tumbledown Cliffs area (Fig. 1). The party remained in the field for 52 days.

During April 1959 a third journey was undertaken, using a new overland route via Mondor Glacier and Mount Cardinall to View Point and then to the Church Point area. The return journey was over the sea ice when it formed in May. Geological survey of the peninsula near Camp Hill was completed and a base map on a scale of 1 : 10,000 was made by plane-table methods.

The last journey, from July to November 1959, took 120 days. Mapping of north-west James Ross Island was completed, the Cretaceous outcrops in the south-east of James Ross Island and on Snow Hill Island were visited, and the previously unknown fossiliferous sediments at Cape Lamb provided valuable evidence in determining the relationships between the ammonite faunas. Plane-table maps were constructed of Bald Head (1 : 10,000) and an area between Lachman Crags and Bibby Point (1 : 20,000).

As a result of these journeys it was possible to establish a sequence in the Cretaceous rocks; detailed observations were also made on the nature of the unconformity between the Cretaceous rocks and those of the James Ross Island Volcanic Group. Structural observations, throwing light on the origin of Prince Gustav Channel, and fossil collections were made. An assessment of the physiography has led to the present description of its evolution.

II. PHYSIOGRAPHY

THE area considered in this report is bounded by lat. 63°10′ and 64°40′S., and long. 56°30′ and 59°00′W. The physiography is a direct reflection of the geology of the area and lends itself to division into two parts upon this basis: a unit comprising Trinity Peninsula in the west, and James Ross Island and its associated smaller islands in the east. The boundary between the two sub-divisions is Prince Gustav Channel (Plate Ia).

At two localities the eastern physiographic type occurs on the mainland of Graham Land. In the north it crosses the tip of Tabarin Peninsula, including Seven Buttresses, Buttress Hill and Brown Bluff. North-west of Tabarin Peninsula the dividing line passes between Joinville and Dundee Islands. The latter island is included in the eastern type.

In the south the division is not so clearly marked where the Cretaceous and Jurassic rocks occur on the mainland at Cape Longing. This is a snow dome with occasional cliffs protruding from the ice at its edges, but its topography is similar to that of Snow Hill Island in the eastern group, and it is therefore included with that type.

1. TRINITY PENINSULA

Trinity Peninsula is composed of three physiographic sub-units: the plateau, the valley glaciers and the ice piedmonts. The plateau is difficult of access due to its precipitous margins and is named the Detroit Plateau (Plate Ib) in the south-west of the area, where it is over 5,000 ft. (1,525 m.) in height. At lat. 63°40′S. it is broken by Russell West and Russell East Glaciers (Plate Ic) but resumes northwards as the Louis-Philippe Plateau with an average height of 4,000 ft. (1,220 m.). A second break, Misty Pass, occurs farther north (lat. 63°29′S.) and beyond this the average height falls to 3,000 ft. (915 m.) (Plate IIa). At the head of Duse Bay there is a considerable break but Mount Taylor (3,200 ft.; 975 m.) may be a remnant part of the original plateau surface. On Joinville Island, across Antarctic Sound, there are traces of a plateau level at 2,300 ft. (700 m.) near Mounts Tholus and Percy (Bibby, 1960, p. 3). The latter marks the farthest point to which the plateau can be traced.

Dissection of the plateaux is occurring by nivation at the head of a set of valley glaciers, which are separated by mountain ridges in the form of arêtes. Good examples of these occur in the vicinity of Russell East and Victory Glaciers, where the mountain peaks are sharply pointed and of the Matterhorn type. This is essentially a reflection of the nature and jointing of the rocks, because metamorphosed greywackes break into sharp angular fragments along many irregular joint planes.

The flow of ice from the valley glaciers coalesces to give an ice piedmont which is present along most of the coast of Trinity Peninsula. It is undulating and often crevassed. Its characteristics accord more with those described by Flint (1947) than by Holmes (1952); it is particularly well developed between Mounts Reece and Wilde, and in the area between Russell East Glacier and Chapel Hill. North of Chapel Hill there is a series of gently sloping discrete glaciers rather than a true ice piedmont, although the appearance of the country is much the same. The small areas of ice between Striped Hill and Crystal Hill, and between Crystal Hill and Bald Head appear to be relatively thin and stagnant. The ice piedmont is well developed on the north-western coast of Trinity Peninsula but it is often broken by high rocky ridges which reach from the plateau to the sea, e.g. Marescot Ridge.

One further feature remains to be noted in connection with the physiography of Trinity Peninsula; this is the difference between the north and north-west coast, from Cape Kjellman to Mount Bransfield including the islands to the north, and the east and south-east coast, from Cape Longing to Hope Bay. In the former area rock exposures are often covered by thick deposits of rime ice, snowfall is heavy and bare ice is the exception rather than the rule. However, in the latter areas accumulation of rime ice is not so heavy, snowfall is relatively light (except in late winter) and bare blue ice is common particularly in coastal regions. This difference is one of climate and caused by the high plateaux intercepting westerly moist winds from the Bellingshausen Sea. It is responsible for great differences in the appearance of essentially similar features on either side of the plateau. Prince Gustav Channel and the James Ross Island archipelago may be regarded as a "snow shadow" area in the lee of the plateaux of Trinity Peninsula.

2. JAMES ROSS ISLAND GROUP

James Ross Island and its associated islands are different in almost every respect from the mainland. The rocks of which they are composed are dominantly volcanic in origin and react to the cold desert erosion cycle in a different way to the metamorphosed rocks of the Trinity Peninsula Series. This is mainly due to the different arrangement of the joint planes, the most strongly developed of which are vertical in the volcanic rocks. The resulting landscape is one of buttes and mesas (Plate Id), more or less well developed according to the stage of the erosion cycle reached.

Where the thick cover of volcanic rocks has been pierced and the underlying Cretaceous sediments are exposed, the effects of winnowing by wind action and erosion by marine action can be clearly seen. The results of wind action are particularly well developed at The Naze, Admiralty Sound and in the lee of Snow Hill and Seymour Islands, where wind-blown sand frequently occurs on the surface of the sea ice many miles from land.

James Ross Island consists of a central ice cap, Mount Haddington (5,340 ft.; 1,625 m.), bounded on its south-west, south and south-east sides by high cliffs and valley glaciers. On the north side there are two rocky promontories: a small eastern one called The Naze and a very extensive western one. The latter terminates at Cape Lachman in the north and at Cape Obelisk in the west, with an average height

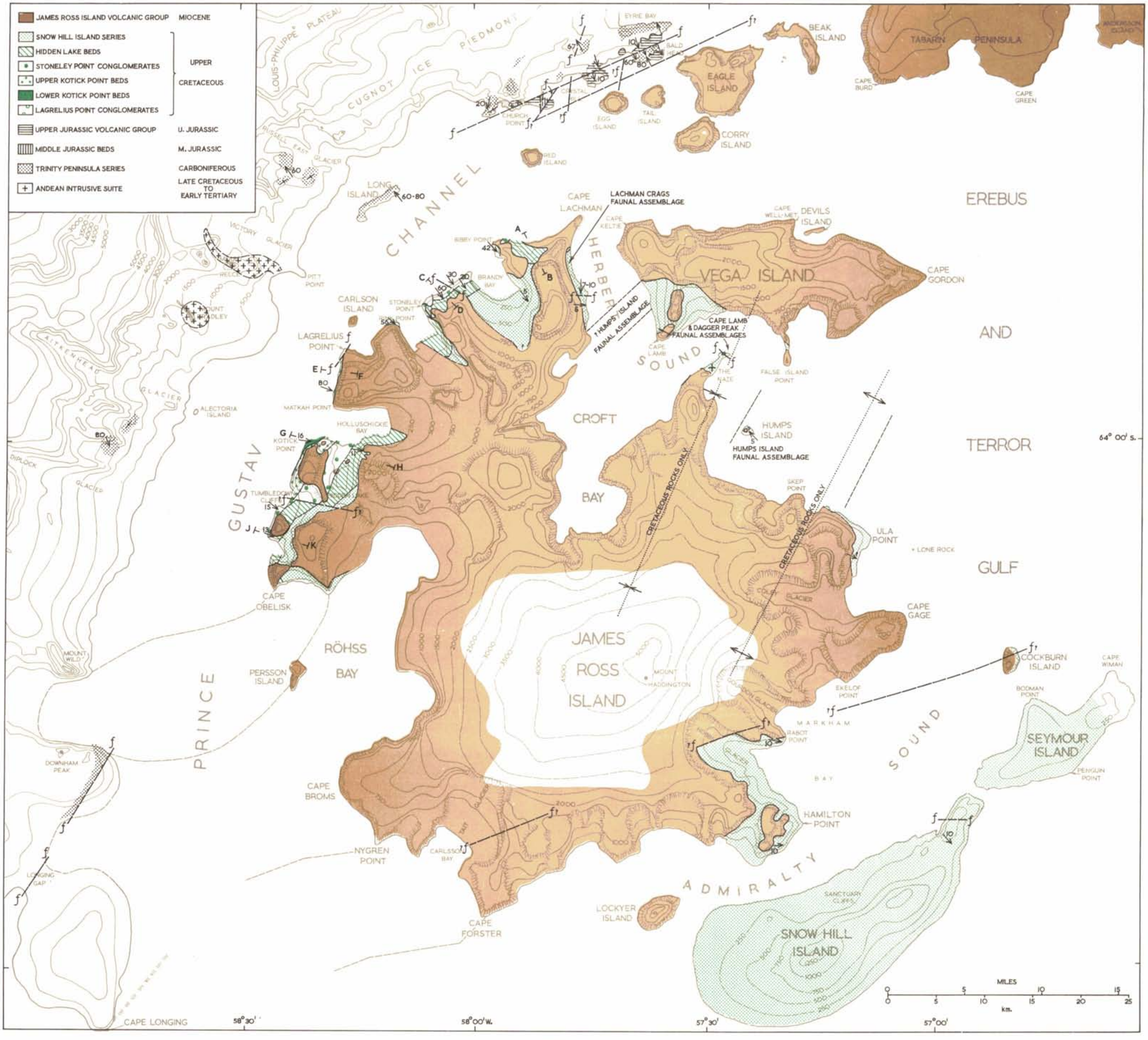

FIGURE 1

Geological map of part of the east coast of Trinity Peninsula, north-east Graham Land, and the James Ross Island group. The station positions are shown and the contours are given in feet. The positions of the cross-sections (A—B, C—D, E—F, G—H, J—K; see Fig. 7) are indicated.

of 2,000 ft. (610 m.). This peninsula is severely dissected and supports at least three important valley glaciers, which are cut off from the main accumulation area of Mount Haddington, and numerous cirque glaciers.

In overall size James Ross Island is 41 miles (66 km.) wide and 45 miles (72 km.) long. It has an area of 1,220 sq. miles (3,160 km.^{2}), of which 875 sq. miles (2,265 km.^{2}) are covered by permanent ice. Exposures of the volcanic rocks in vertical cliffs around its coasts are abundant. Seymour and Snow Hill Islands to the south-east and Vega Island to the north are the largest of the subsidiary islands. The two latter islands have their own ice caps as do Corry, Eagle and Lockyer Islands of the smaller ones. The other ten islands of the group have no ice caps and, with the exception of Humps and Cockburn Islands, they are composed of rocks of the James Ross Island Volcanic Group; they often rise sheer from the sea to heights over 1,000 ft. (305 m.). Humps and Cockburn Islands have a base of Cretaceous sediments upon which the volcanic rocks rest unconformably.

James Ross Island is separated from Trinity Peninsula by Prince Gustav Channel which varies in width from 5 to 15 miles (8 to 24 km.). The smaller islands are mainly grouped in the northern part of the channel and some are within 1 mile (1·6 km.) of the mainland. The geographic distribution of the smaller islands of this group can be accounted for satisfactorily by the geological structure of Prince Gustav Channel. It is considered that Prince Gustav Channel is a fault zone which has been active during several time periods. In post-Pliocene times an uplift of over 1,000 ft. (305 m.) occurred to the east of the fault and dissection of the rocks exposed by this movement has determined the distribution of the more northerly of the islands, i.e. Red Island to Eagle Island. It is possible that fault lines divided the whole of this area into a number of blocks of which the present-day islands are the eroded remnants.

The positions of Carlson and Persson Islands can be explained by a similar argument. Snow Hill and Seymour Islands are different in structure and appearance. There is evidence of extensive uplift in this area since Pliocene times (Pliocene Pecten Conglomerate has been found near the summit of Cockburn Island at 1,480 ft. (450 m.) (Croft, 1947) and these islands were probably an extension of the Cretaceous of James Ross Island. They have either remained outside the influence of the eruptions from Mount Haddington or have since lost their volcanic cover by severe erosion. James Ross Island itself undoubtedly owes its position to the main volcanic cone of Mount Haddington.

The marked radial distribution of bays and headlands on James Ross Island is indicated on Fig. 1. Several factors have been important in producing this landform pattern, amongst them the geological structure of the island, its original form (which was that of a volcanic cone centred on Mount Haddington) and the subsequent effects of glaciation. The following glacial history, which throws light on the geomorphological evolution, has been reconstructed.

Four major glaciations have been recorded by Péwé (1960) from eastern Antarctica in the vicinity of McMurdo Sound. From various observations it is believed that evidence for at least three stages of glaciation can be found in the area described in this report. Evidence for the first and last of these is clear and comparison with Péwé's McMurdo and Koettlitz glaciations is good.

In the north-west of James Ross Island between Stoneley Point and Cape Lachman there are several well-developed U-shaped cols at heights ranging from 500 to 1,000 ft. (152 to 305 m.). The most important of these is east of Stoneley Point, where erratics derived from the mainland were found at a height of 1,000 ft. (305 m.) and a set of striae from south-west to north-east was observed. At numerous localities in the vicinity of Brandy Bay and from west to east in Herbert Sound as far as The Naze (Croft, 1947) boulders of mainland derivation have been found. Those of metamorphic origin had taken a fine polish from wind action.

That ice of this glaciation had reached a thickness of more than 1,000 ft. (305 m.) in Prince Gustav Channel cannot be doubted. It would also appear that ice from the mainland flowed round the edges of the Mount Haddington ice cap and penetrated the Weddell Sea in the Erebus and Terror Gulf area via Herbert Sound. Undoubtedly much of this ice would also have flowed northwards between Corry and Vega Islands, and its excavating action would clearly account for the great depth of the sea between Vega Island and Seven Buttresses on Tabarin Peninsula.

Evidence for glacial stages corresponding to Péwé's Taylor and Fryxell glaciations is more difficult to find. So far it has not been possible to differentiate between these stages in north-west Graham Land. The moraines of the Hope Bay area, which are no longer ice-cored and upon which (close to Depot Glacier) ventifacts of Jurassic volcanic tuffs occur are the only remains yet discovered. Some of the dry valleys of James Ross Island, e.g. in the Brandy Bay area, may have some connection with these stages of glaciation.

The similarities to the last glacial re-advance, the Koettlitz glaciation, are striking. Péwé (1960, p. 77) states: "The deposits are well preserved and distinct; they are easily differentiated from the older glacial drift because the moraines of the Koettlitz glaciation are still filled with stagnant glacial ice. The ice-cored moraines exhibit well developed constantly shifting knob and kettle topography." This description fits perfectly the moraines of many of the cirques of James Ross Island. Examples can be found in the Hidden Lake area (Fig. 6; Plate Id).

Later Péwé (1960) states "No ventifacts have formed on the shifting topography of the ice-cored moraines. The moraine of Koettlitz age flanking Garwood Glacier is compound; two advances are evident. Both outer and inner moraines lie within 200 yd. (183 m.) of the present glacier front." Again, these remarks accord closely with the nature of the glaciers in the Hidden Lake area of James Ross Island. Many of the cirque glaciers have a shorter distance than this between their present ice fronts and the terminal moraines from which they have retreated.

The sequence of events which led to the present physiography of James Ross Island began with the onset of glacial conditions at a time when the landscape was a composite cone of lavas and tuffs emanating from Mount Haddington, a rough topography of crags and valleys possibly partly submerged by the sea. Small cirque glaciers like those found at present in the area north of Cape Obelisk (Fig. 6) developed, and as conditions became more severe they extended to form a pattern of valley glaciation. The local ice cap of Mount Haddington became established and advanced, and erosion instead of being confined to the valleys became regional. The ice in Prince Gustav Channel thickened as the ice caps of Mount Haddington and the mainland coalesced, gradually halting the flow of ice from the valley glaciers of James Ross Island. The more northerly glaciers were active for a longer period of time than the more southerly ones, and the difference in degree of erosion between the Cape Lachman area and the more southerly areas can thus be explained. Conditions of maximum glaciation were reached and the main striation patterns were developed. Ice from the mainland invaded parts of James Ross Island, over-riding the local ice, and was responsible for the deposition of erratics from the mainland over the north-west and western parts of the island. Evidence concerning the extent to which deglaciation occurred is lacking. If the conditions appertaining were similar to those of the McMurdo Sound area, it would be likely that almost complete deglaciation took place in the long period between the McMurdo and Taylor glaciations. The oscillations of the Taylor and Fryxell glaciations, if they occurred here, only served to emphasize the topography of the major ice drainage lines already established at the commencement of the McMurdo glaciation. Continued recession established what must have been practically the present-day ice pattern. Relict and relatively stagnant ice still caps most of the mesas of James Ross Island, becoming more frequent and thicker near the Mount Haddington ice cap. As the major source of ice retreated, the glaciers in turn became stagnant. The one which entered Brandy Bay disappeared completely, as did one or two of the small cirque glaciers.

A brief late period of re-advance commenced, the equivalent of the Koettlitz glaciation, but the general trend towards deglaciation re-asserted itself and continues slowly at the present day. The glacier at the head of the bay south of Stoneley Point is stagnant but the one at the head of Holluschickie Bay is more active. It is now also detached from the main ice cap and may be expected to deteriorate in the same way as those immediately to the north. However, the glaciers of the south and south-western part of James Ross Island have not reached this state of retrogression. This is probably due to the influence of aspect on glacier regime. These glaciers have a gentle surface profile but they are surrounded by cliffs often over 1,000 ft. (305 m.) high, e.g. Hobbs and Gourdon Glaciers. Nivation of the head walls is active, as is frost-shatter of the exposed rock surfaces along the flanks. The vertical jointing greatly aids this phenomenon. Ice falls from the main Mount Haddington ice cap above are spectacular, though it is uncertain how much of the ice in the glacier is derived by this means.

III. GENERAL STRATIGRAPHY

THE rocks within the areas described belong to five different geological periods: the (?) Carboniferous, Jurassic, Cretaceous, Miocene and Pliocene (Figs. 1 and 2). The regionally metamorphosed greywackes and shales, which are the predominant rock type on Trinity Peninsula, have been ascribed to the (?) Car-

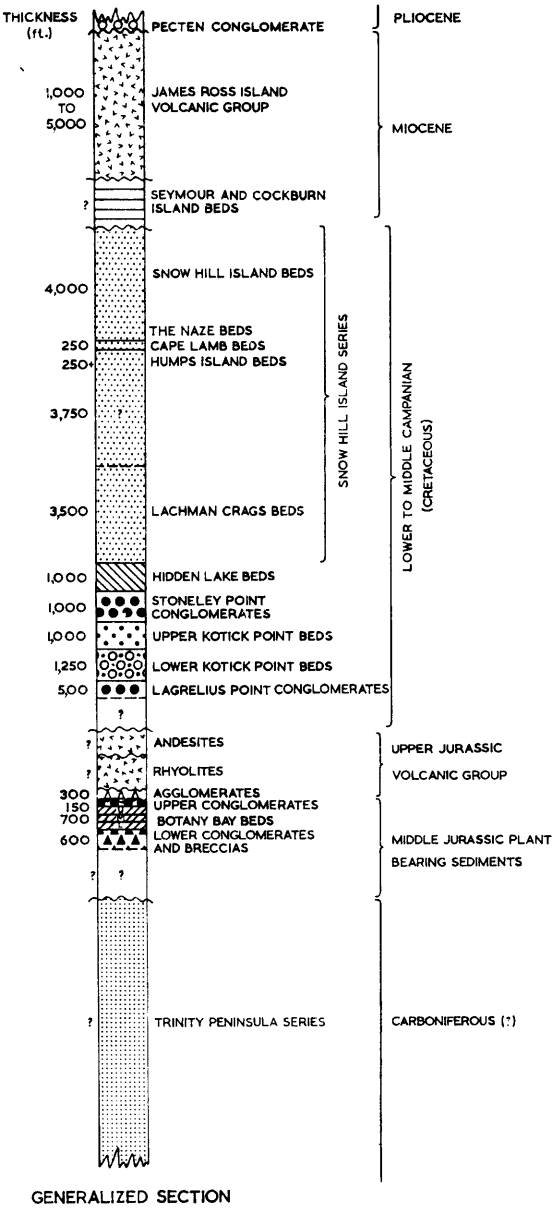

FIGURE 2

The generalized stratigraphic succession in north-east Trinity Peninsula and the James Ross Island group.

boniferous period (Adie, 1957, p. 1) and are the oldest rocks exposed within this region. Structurally, they consist of a series of complex folds, steeply dipping in places. They have recently been the subject of a detailed investigation (Aitkenhead, 1965) and do not come within the scope of this report, but their erosion through succeeding geological periods has provided the Mesozoic rocks with one of their basic constituents.

Beds which can be assigned to the Middle Jurassic occur in two localities: at Hope Bay (Mount Flora) and in the Botany Bay area. In neither locality is the contact with the Trinity Peninsula Series exposed, although at Hope Bay the relationship is certainly one of angular unconformity. At Botany Bay the two successions are separated by a fault. The Jurassic beds at Hope Bay have been described as lacustrine (Andersson, 1906) and deltaic (Croft, 1947) in origin. These conclusions are confirmed by the presence of large, delicate and undamaged specimens of terrestrial plants, the presence of insect elytra (Zeuner, 1959), the absence of marine organisms and the general nature of the deposits. These beds are coarse at the base and grade into shales at the top, which must have been deposited under quiescent conditions as the basin filled. The shales are lenticular and evenly laminated. One horizon showed symmetrical ripple-marks with a wave-length of 2–3 in. (5–7·6 cm.).

At Botany Bay the sequence, though basically similar, contains considerably more coarse clastic material. The plant remains are similar to those of Mount Flora but they are broken and the shales are less evenly laminated. There are beds of white well-sorted sandstones such as are commonly associated with offshore sand bars. Some very poorly preserved casts of gastropods were the only faunal remains found. Symmetrical ripple-markings were more frequent than at Mount Flora. The balance of evidence suggests that the beds at Botany Bay are a shallow-water marine facies laid down under more turbulent conditions than those operating at the same period near Mount Flora.

A sequence of rhyolitic rocks is conformable with the Middle Jurassic sediments at Hope Bay. Rhyolites also occur as a small patch at Camp Hill, and in a headland at Crystal Hill (Plate IIIa) where there is no indication of their relationship to other rocks. They are accorded a Jurassic age because of their similarities to the Hope Bay sequence. Andesites are associated with the Camp Hill rhyolite, and they also occur at Bald Head where they rest unconformably on the Trinity Peninsula Series. The allocation of a Jurassic age to these rocks is based partly on their association with Jurassic rhyolites and partly upon petrographic similarities to other andesitic rocks of proved Jurassic age in Graham Land. Agglomerates also occur at Camp Hill and Crystal Hill.

A further outcrop of Jurassic rocks occurs near Longing Gap, where impressions of the Upper Jurassic ammonite *Perisphinctes* sp. have been discovered in a series of gullies. This section had previously been described by Standring (1953), who also recorded the occurrence of extremely poor impressions of lamellibranchs and ammonites. The sediments consist principally of thinly-bedded grey and black siltstones, and shales with sandstones and occasional lenticular limestone bands. The sequence may contain tuffaceous bands which could relate it to the Upper Jurassic Volcanic Group. A section of 353 ft. (107·5 m.) was measured by Standring in this area.

The sediments are horizontal or very gently dipping south-eastwards but at the northern end of the outcrops steep south-easterly dips were recorded. Standring was of the opinion that the beds were affected by a fault zone which he envisaged as passing through Longing Gap. This would appear to be confirmation of the continuance, at least as far as Cape Longing, of the structure which affects the Cretaceous rocks of the west coast of James Ross Island and which has been attributed to fault movements along the line of Prince Gustav Channel.

Only one other section has been noted in this area, again by Standring, at Cape Longing itself. Here, the lithology is coarser than in the Longing Gap area, containing more conglomerates and sandstones, and it is closely allied to the sediments in the Tumbledown Cliffs area of James Ross Island. Faunal remains tend to bear out the lithological comparisons and it would therefore seem reasonable to believe that the Upper Jurassic is represented by the outcrops near Longing Gap, that the Upper Cretaceous is present at Cape Longing and that the boundary between the two is hidden beneath the ice dome of Cape Longing.

An hiatus occurs in the succession between the Upper Jurassic sediments of Cape Longing and the Lower to Middle Campanian of the Cretaceous System on James Ross Island. That a Lower Cretaceous sequence was deposited and has since been largely removed by erosion is indicated by the presence of *Aucellina andina* in a pebble from the Cretaceous (Stoneley, 1953) and by the nature of the constituents of the Cretaceous conglomerates. This includes a large amount of derived glauconitic sediment, which is not represented in the Jurassic rocks as far as can be ascertained from the fragmentary record that has been preserved.

The surface outcrop of Cretaceous sediments is confined to James Ross, Vega, Snow Hill, Seymour, Cockburn and Humps Islands. They have also been reported from Persson Island (Operation Tabarin localities 5135–36) but a prolonged search failed to locate them. It is assumed that Cretaceous detritus found on the north-east corner of the island was derived by ice flow from the vicinity of Cape Obelisk.

The most extensive outcrops of Cretaceous rocks on the west coast of James Ross Island extend in continuous sections from near Cape Lachman to Rink Point and from south of Lagrelius Point to Cape Obelisk. The two outcrop areas are separated only by the volcanic rocks of the Lagrelius Point area. The rocks of these areas have been correlated on lithological similarities, because the palaeontological evidence is scant. As will become apparent, the sequence is a gradational one and thus the exact boundaries between the groups of beds have been chosen on an arbitrary basis.

In the east there are extensive outcrops of Cretaceous rocks on Snow Hill, Seymour and James Ross Islands. The Cretaceous of Snow Hill Island has been described by Nordenskjöld (1905), and the name Snow Hill Island Series was proposed for it and applied loosely. In this report the lower limit of the Snow Hill Island Series has been defined as the point where the sandy shale beds (Hidden Lake Beds) of west James Ross Island become predominant. The Snow Hill Island Series is viable on both lithological and palaeontological grounds. It is characterized by loose uncemented sandstones which contain a distinctive fauna of ammonites and the calcarinate worm *Rotularia*. *Inoceramus* is frequent in the beds below it, which are in general composed of conglomerates, coarse moderately well-cemented sandstones and sandy shales with some true shales. Ammonites are infrequent.

On Seymour Island the Cretaceous beds are overlain with angular unconformity by the Lower Miocene Seymour and Cockburn Island beds (Standring, 1956). The lithology of the Tertiary rocks is very similar to that of the Cretaceous and it was only by careful mapping that they were differentiated.

These beds are followed stratigraphically by the basalts and basaltic tuffs of the James Ross Island Volcanic Group. The relationship between the volcanic rocks and the sediments of the Tertiary and Mesozoic is very clearly an unconformity of great magnitude. The volcanic rocks come into contact with all the divisions of the Cretaceous sediments so far recognized. The James Ross Island Volcanic Group is widespread in extent, ranging from Dundee and Paulet Islands in the north to beyond the Seal Nunataks in the south. The basalts were erupted from a number of centres, the most important of which was Mount Haddington, and they spread over a landscape of Cretaceous rocks and into the surrounding seas. Here they formed pillow lavas and bedded tuffs and agglomerates, which are found at various levels in the succession and indicate a period of crustal instability with fluctuating sea-levels.

Little is known of post-Miocene conditions apart from the discovery of a thin Pliocene *Pecten*-bearing conglomerate on the summit of Cockburn Island (Andersson, 1906; Croft, 1947). This is at a height of 1,480 ft. (450 m.) above sea-level and therefore its deposition must have been followed by a considerable uplift of the land. In the absence of any other sediments, it is not possible to date this movement with any degree of certainty.

IV. TRINITY PENINSULA SERIES

A DESCRIPTION of the metamorphic rocks of the Trinity Peninsula Series has already been published (Adie, 1957). They consist of greywackes of differing shades of colour (generally in the range pale grey-green to very dark grey though they may sometimes be brown), siliceous mudstones and siltstones, and shales, all of which are black or very dark grey. Local variations are common; the shales have been autobrecciated and incorporated into the greywackes at Hope Bay; coarse grit bands occur at View Point and the siliceous mudstones, siltstones and light-coloured quartzose beds are locally dominant on Tabarin Peninsula (Croft, 1947).

The greywackes, mudstones and siltstones are often massive but sometimes there is a faint flaggy parting. The shales, on the other hand, are often very well cleaved and compressed, approaching phyllite in appearance, as at View Point and Long Island.

The finer-grained, better-structured rocks, such as the shales, are almost absent from the macro-constituents of the Mesozoic rocks. They were destroyed during the cycle of erosion prior to the deposition of the Jurassic rocks. Similarly, rocks which have passed through two cycles of erosion to be deposited in the Cretaceous are the most massive and compact of the suite of metamorphic rocks. The shaly and slaty boulders which occur in the Cretaceous are probably derived from the Jurassic rocks and not directly from the Trinity Peninsula Series.

The Trinity Peninsula Series was examined briefly in two localities: at Hope Bay, where observations were of a structural nature and concerned with the unconformity between the metamorphic rocks and the Middle Jurassic sediments, and at Bald Head. In the latter area observations were again mainly structural and concerned with the unconformity with the Jurassic volcanic rocks. From the limited observations, it appears that the greatest disturbance of the metamorphic rocks occurs in the vicinity of Prince Gustav Channel. Dips between 70° and vertical were recorded at View Point, Bald Head and Long Island (Croft, 1947), whereas dips of only 25–30° are common near Hope Bay. This may have significance with regard to the fault zones of the channel.

V. MIDDLE JURASSIC SERIES

1. Hope Bay Area

The Middle Jurassic beds of Hope Bay (Fig. 3) have received attention from all geologists who have visited the area, principally on account of the remarkable profusion of plant remains in their upper horizons. The Middle Jurassic sediments occur only in the north and west faces of Mount Flora and it is unlikely that they crop out under the ice of Tabarin Peninsula (Ashley, 1962). The west face of Mount Flora (Plate IIIb) is not readily accessible but the north face provides excellent exposures. The contact with the underlying beds of the Trinity Peninsula Series is not exposed, but the difference in direction of dip between the two series is so marked there is no doubt that it is an unconformity.

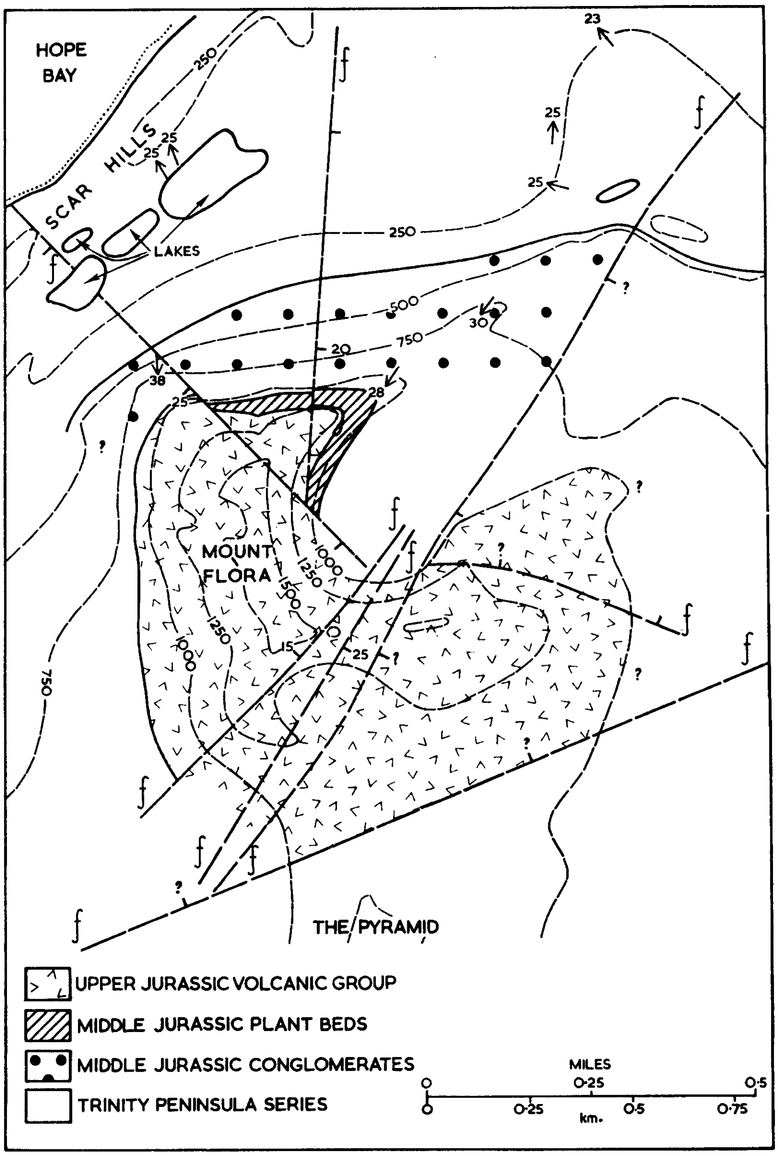

FIGURE 3

Geological sketch map of Mount Flora, Hope Bay, Trinity Peninsula. The contours are given in feet.

Andersson (1906) recognized the distinction between the upper volcanic horizons of Mount Flora and the lower plant-bearing beds. These two divisions are conformable and there are many sections on the north face of Mount Flora which demonstrate this. Bands of tuff and agglomerate, similar to those of the lower part of the tuff succession, are interbedded with dark carbonaceous mudstones and shales which carry plant remains. The tuffs are characterized by blocks of cream-coloured fossil wood, which are similar to specimens from the vicinity of Camp Hill.

The lower part of the sedimentary succession, that which first appears at the top of the screes which obscure the plane of unconformity, is composed mainly of coarse conglomerates with occasional impersistent bands of both coarse and fine sandstone. The boulders in the conglomerates which are derived from the Trinity Peninsula Series may reach 4–5 ft. (1·2–1·5 m.) in diameter but they are generally 1–2 ft. (0·3–0·6 m.) in size. At 400 ft. (122 m.) there is a band of pale grey sandstone which was considered by Croft to be a tuff. If this is so, it is the first evidence of volcanicity in the sequence, though at this time it was probably at some distance.

Alternations of coarse and fine conglomerates with occasional sandstone and mudstone beds, impersistent and containing infrequent plant remains, occur up to a height of 700 ft. (213 m.) from the base of the section. At this level shales and mudstones begin to predominate over the coarser elements in the sequence. The last 300 ft. (91 m.) are dominantly mudstones and shales, but in the top 60 ft. (18 m.) tuffs and some lenticular bands of agglomerate occur at intervals.

The measured section (Table I) has been compiled from several shorter sections, because scree and moraine obscure parts of the sequence. The upper 500 ft. (152 m.) was measured along the arête which leads to the top of the north face from the vicinity of the scientific station. The main feature of the beds

TABLE I

SUCCESSION IN THE MIDDLE JURASSIC ROCKS AT MOUNT FLORA, HOPE BAY

	ft.	m.	
Interbedded chert, agglomerates and tuffs			Upper Jurassic Volcanic Group
Sandstones and shales	100	30·5	Well-preserved Jurassic plant remains in shales; occasional sandstone partings
Mudstones	90	27·4	Dark grey, occasionally laminated
Bedded sandstones	90	27·4	Some conglomeratic intercalations
Conglomerate	175	53·3	Some shale bands with poorly preserved plant remains
Conglomerate, mudstone and sandstone	30	9·1	
Conglomerates	110	33·6	Boulders of greywacke 0·5–1·0 ft. (15–30 cm.) in diameter
Grey sandstone	10	3·0	Possibly a tuff
Conglomerates	300	91·4	Unsorted greywacke boulders; large size range
Grey conglomerate	5	1·5	Conglomerate in a grey sandy matrix
Conglomerates	30	9·1	Coarse and unsorted
Conglomerates and cherts	3	0·9	1–3 in. (2·5–7·6 cm.) pebbles in conglomerate, with fine chert bands
Conglomerate	60	18·3	Greywacke boulders 1–4 ft. (0·3–1·2 m.) in diameter
	1,003	305·5	

(Measurements were compiled from several sections but principally from the north-east spur of Mount Flora) in this section is their impersistence. Most of them cannot be traced for more than 400 yd. (366 m.); the major plant-bearing horizon, which is over 100 ft. (30·5 m.) thick on the north-east spur of the north face cannot be traced at all on the north-west spur. Coarser mudstones and sandstones containing a few imperfectly preserved plant remains take its place, but a thin (8 ft.; 2·4 m.) band of shale may represent it. Local erosional unconformities are common.

2. BOTANY BAY AREA

Botany Bay (Fig. 4) is on the northern coast of Prince Gustav Channel and it is east of a prominent landmark on this coast, Church Point. This coast has low cliffs varying in height from 50 to 100 ft. (14 to 30·5 m.) and in which the structure of the Middle Jurassic sediments can be well seen; the ground rising steeply beyond these cliffs is mantled with the detritus of frost-shattering through which small crags penetrate. Camp Hill, rising to over 400 ft. (122 m.), is the highest point at which the sediments of Middle Jurassic age have been found.

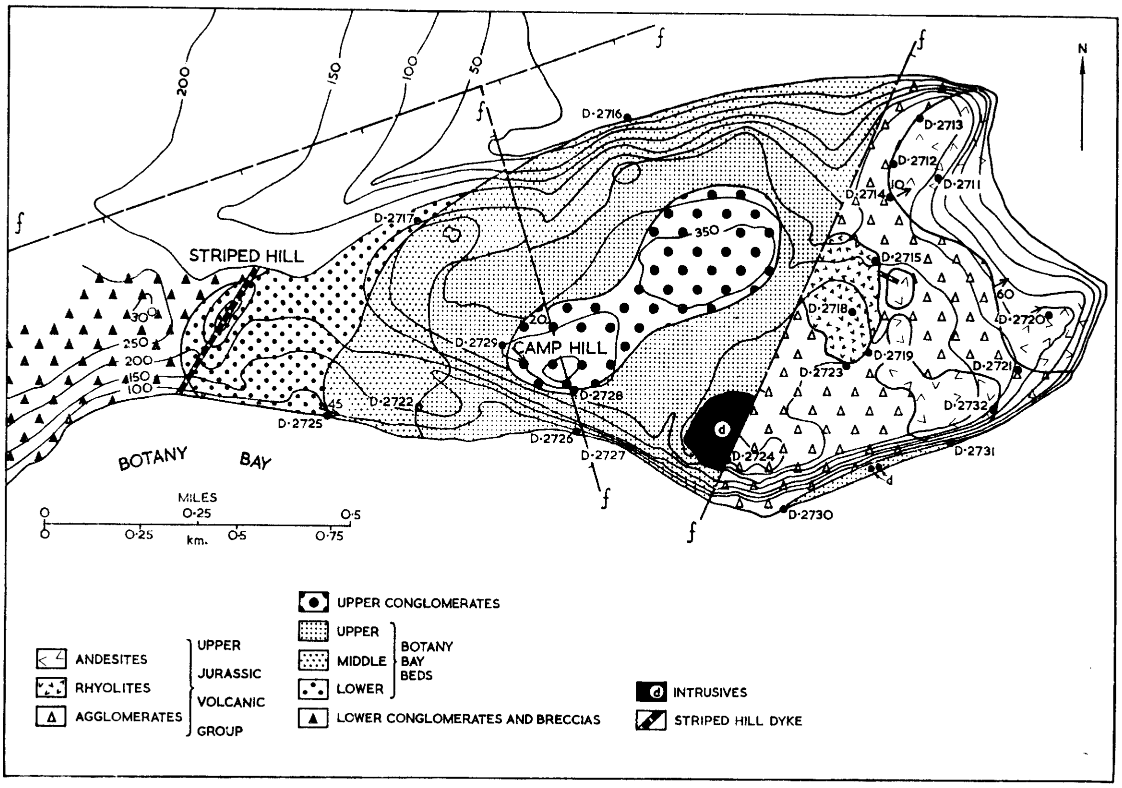

FIGURE 4

Geological sketch map of Camp Hill and the coast of Botany Bay, east coast of Trinity Peninsula. The station positions are shown and the contours are given in feet.

The sequence within the Middle Jurassic rocks of the Botany Bay area is:

	ft.	m.
Upper conglomerates	150	46
Upper Botany Bay beds	250	76
Middle Botany Bay beds	200	61
Lower Botany Bay beds	250	76
Lower conglomerates and breccias	600	183
Base not seen		
	1,450	442

At the top of each of the groups of the Botany Bay beds is a well-washed white sandstone, which is current-bedded, ripple-marked, generally 15–20 ft. (4·5–6·1 m.) thick and identified as *ortho*quartzite. These sandstones probably indicate periods of slight uplift when shallow-water conditions became widespread throughout the area. Specimens were collected from each of the beds but so far they have only been cursorily examined.

a. *Lower conglomerates and breccias*

These beds are massive breccias at the base, passing upwards into well-bedded conglomerates as the constituent fragments become more rounded. The matrix is a dark sandstone and the boulders in the breccias are entirely derived from the Trinity Peninsula Series, which had been metamorphosed prior to the deposition of the Middle Jurassic beds.

The beds in contact with the intrusion at Church Point are vertical and from here towards the head of Botany Bay the dip decreases gradually. The base of this sub-division is arbitrarily assumed to be in the vicinity of the Striped Hill dyke (Fig. 4), since it is here that shales become noticeably more abundant in the sequence. The conglomerate and breccia beds have not yielded definitely identifiable plant remains, although some highly contorted specimens were found on the col separating the smaller peak of Church Point from the larger one.

The conditions of deposition of the beds were, judging from the boulders embedded in the rocks, of a violent nature and near to a shoreline because the boulders are mainly sub-angular.

b. *Botany Bay beds*

The outcrop of the lower Botany Bay beds extends from the Striped Hill dyke to the first of two beds of white sandstone which occur at the head of Botany Bay. As is to be expected from the gradational nature of the sediments, these beds are mainly black conglomerates separated by dark sandstones and shales. The constituents of the conglomerates are rounded to a greater degree than those in the beds beneath them but otherwise they are similar. The grade size becomes smaller towards the top of the sequence. The sandstones and sandy mudstones have yielded an appreciable flora which is often well preserved.

The boundary between the lower and middle Botany Bay beds is a bed of white sandstone 15–20 ft. (4·5–6·1 m.) thick, which is current-bedded and ripple-marked. The conditions of deposition were such that the sediments coming into the area were becoming finer. Towards the end of the period there were clearly shallow-water conditions for a time, and the well-sorted white sandstone was laid down possibly as an offshore reef.

The trend towards finer sediments continues in the middle Botany Bay beds which crop out on the shore from the top of the lower white sandstone to the base of the upper one. They are composed of black, extremely fissile mudstones and shales which contain a large amount of plant material. The plant specimens are well preserved but they are so small and shattered as to be virtually uncollectable. A considerable number of ironstone nodules occurring along well-marked horizons characterize the upper parts of this sequence. Gastropod remains were found in several of these but they were too poor even for generic identification. Thin dark conglomerates are abundant but subordinate.

Another bed of white sandstone, similar in character to the first, separates the upper division from the middle one. This sandstone is overlain by a band of black paper shales, which are barren except for a few bands containing poor macerated plant remains near its base. Above the paper shales, sandstones and shales alternate and plant remains are again common towards the top of the sequence. Dark conglomerates are subordinate.

The fairly quiet depositional environment continued with occasional disturbances which gave rise to the conglomeratic intercalations.

c. *Upper conglomerates*

These are a varied group of light and dark sandstones and conglomerates which crop out in the cliffs on the seaward side of Camp Hill. They exhibit the synclinal structure of the area quite well and are cut by a small fault which can be seen in the coast section and in the cliffs above. A few complete but poorly preserved fern fronds were found in the sandstones, the finer of which also contained the usual very fragmentary plant remains characteristic of the shales of lower horizons. Numerous pieces of cream-coloured fossil wood were found, especially lying on the slopes of Camp Hill facing the mainland, but none were seen *in situ*. At Hope Bay, wood preserved in this manner is associated with the onset of volcanicity.

Conditions at the time of deposition of these beds had undoubtedly reverted to those which prevailed earlier in the sequence, becoming fairly turbulent. Current-bedding is well developed. No fragments other than those derived from the Trinity Peninsula Series were seen anywhere in the succession. The distribution of these sediments is indicated in Fig. 4.

VI. UPPER JURASSIC VOLCANIC GROUP

1. AGGLOMERATES

The agglomerates in the vicinity of Camp Hill are distinctive, since their phenoclasts are rounded instead of angular, sedimentary in origin but set in a tuffaceous matrix. They were originally described by Croft (1947, Pt. 1) under the name of "Verdi Hill conglomerates", and they have posed a difficult problem in the field. Their extent is shown in Fig. 4 but their outcrop is confined to the vertical, crumbly and dangerous coastal cliffs with a few very small outcrops on the top of the promontory.

These beds are variable in lithology which tends to make correlation difficult over small areas. At the base of the coastal cliffs (D.2730) they have a very marked yellow-green tuffaceous matrix. Their constituent cobbles and pebbles are wholly derived from the Trinity Peninsula Series by way of the Middle Jurassic sediments. Croft (1947, Pt. 1, p. 8) has stated that they are more water-worn than the pebbles in the Middle Jurassic beds, but this is debatable. At the top of the cliffs the beds are darker and very similar to the Middle Jurassic conglomerates. They were assumed to be the same conglomerates until the presence of blocks and fragments of yellow tuff were noted at stations D.2723 and 2724. These tuffs, which do not occur in the Middle Jurassic conglomerates, are composed almost entirely of quartz and feldspar, and are moderately chloritized. At the eastern end of the promontory the lithology changes. The greenish matrix is present again and the rock includes large boulders of rhyolite (D.2721.1, 2).

Stratification is not developed and there is only a vague hint of current-bedding at a high inaccessible place in the cliffs. No structural work was attempted though a brief examination of one section indicated that the orientation of the pebbles is random. However, besides the presence of a tuffaceous matrix and angular tuff and rhyolite fragments, many of the mudstone and greywacke pebbles were found to be broken. This could be confused with frost-shattering due to the mode of weathering of the rock but in places where the other half of such a pebble was to be expected it was not found. The conditions of deposition could therefore be as follows. Volcanic vents of an explosive nature burst through a country rock which was composed predominantly of Middle Jurassic conglomerates of which an example occurs at Camp Hill. The conglomerates were shattered and deposited in a tuff matrix. Later, lava flows and previously consolidated tuffs were disrupted by the explosions and they were included in the sediments being deposited. Thus these rocks are of explosive origin, forming a basement on to which the later volcanic rocks were erupted. They are a highly variable and probably diachronous group of beds depending for their content on the nature of the parent rock, occurring at the start of volcanicity in any area and probably contemporaneous with the rhyolitic group of rocks in adjacent areas. There is some doubt whether they are marine or terrestrial but, if they are marine, then they are of shallow-water origin.

The basal rocks on the north side of Crystal Hill (D.2745) are of a different character but they are presumed to be of the same origin. The country rock through which the vents burst here was the Trinity Peninsula Series. This fractured into blocks and slabs and was deposited as a tuff-breccia. From the nature of the beds it is clear that no time correlation can be drawn between the rocks of these two areas. The rocks of Crystal Hill were almost certainly deposited in water, because some of the finer constituents show bedding.

2. RHYOLITES

The first burst of volcanism in the Jurassic in this area was of a rhyolitic nature. The rhyolites are widespread and they occur on Joinville Island (Standring, 1956; Bibby, 1960), at Hope Bay, in the north of Prince Gustav Channel and in the Cape Disappointment—Gemini Nunatak area of the Oscar II Coast (Adie, 1953).

The rhyolites are grey-green weathering rocks that reach their greatest development at Crystal Hill (Plate IIIa). On its eastern face they form columnar-jointed flows of great thickness. If their dips are interpreted as being original, they have their origin along the fault line which trends northward. This agrees well with the emplacement of the Church Point intrusion along the same fault and also with other minor intrusions in the Church Point area.

Two specimens of the Crystal Hill rocks were examined in thin section, a rhyolite (D.2740.1) and a rhyolitic tuff (D.2741.1). Neither contained the almandine garnet described by Adie (1953) as occurring in these rocks though garnet is common. In the rhyolite (D.2740.1) quartz is the dominant constituent; it occurs in the groundmass as phenocrysts and features largely in the composition of the numerous inclusions. Small unidentifiable crystals of pyroxene and phenocrysts of orthoclase and albite-oligoclase are present. The groundmass is crystalline and the microlites emphasize the flow structure. Calcite is present but chloritization is not well developed. Apart from these points, they are similar to the rocks described by Adie (1953). The rhyolitic tuff (D.2741.1) shows increased chlorite in the matrix but otherwise it is composed of quartz and orthoclase with aggregates of fine broken crystals and chlorite in the groundmass.

The outcrop of rhyolite on the promontory near Church Point (Fig. 4) is so small that it provides little insight into the stratigraphical relations. Specimen D.2718.1 which was taken from it is microcrystalline with very few phenocrysts. Quartz, orthoclase and plagioclase occur as laths and equigranular anhedral crystals. Infrequent small phenocrysts are generally plagioclase and there are occasional small aggregates of a pyroxene. Calcite is abundant and the groundmass is heavily chloritized. No epidote is present.

The rhyolites of Hope Bay have a good vertical development (over 700 ft. (213 m.) thick) of well-bedded tuffs and lavas, and there are also reports of rhyolitic rocks on the north-west side of Hope Bay at Contact Point. They were ice-covered during visits in 1958 and 1959, but they are reported to have an unconformable relationship with the Trinity Peninsula Series. The rocks of this area have been described by Nordenskjöld (1905), Andersson (1906), Bodman (1916) and Croft (1947).

No true rhyolites have been found at Bald Head but boulders of rhyodacite were found in an andesitic tuff (D.2772.1), and a dacitic lava was interbedded with lavas of a more andesitic composition (D.2764.1).

In specimen D.2772.1 the groundmass is cryptocrystalline but there are numerous phenocrysts of plagioclase which have been heavily sericitized. Phenocrysts (probably pseudomorphs) of chlorite, often with a fibrous structure, are present. The groundmass contains a considerable amount of quartz and globular microlites of other minerals which give it a high relief. The lava contains plagioclase phenocrysts with an oligoclase-andesine composition. There is a little biotite, much chlorite and a few small quartz phenocrysts; flow banding is well developed.

3. ANDESITES

Prior to the present investigation andesites had not been reported from this area. The nearest approach to their discovery was when a series of flows were mistaken for an intrusion (Croft, 1947, Pt. 1). They were found to be present in two areas: at Bald Head and on the eastern tip of the promontory which extends eastwards from Camp Hill. In both places the sequence is thin but essentially similar. Two basal lava flows, each about 10–15 ft. (3–4·5 m.) thick, are separated by tuffs varying in thickness from 0 to 50 ft. (0 to 15 m.). They form well-marked and easily mapped features. In both occurrences the uppermost beds of the sequence are ill-defined because of scree cover, and they appear to be a series of thin lava flows.

The andesites are dark grey, brown or blue-black in colour, often weathering to red-brown. They possess no free quartz except where it occurs as inclusions of the bedrock or as a secondary mineral. The plagioclase is characteristically of two generations, being present as euhedral or sub-euhedral phenocrysts with a composition in the andesine-labradorite range. Some of the phenocrysts show resorption phenomena and enclose parts of the groundmass. The composition of the plagioclase in the groundmass was not determined. Augite is the pyroxene and it occurs as euhedral phenocrysts. It is often altered to chlorite round its edges, and ilmenite, calcite and a little pyrite are present. The groundmass is composed mainly of plagioclase laths in which an incipient to good flow structure is developed.

In certain of the rocks the pyroxene may be hypersthene (D.2713.1) and alteration to biotite is common. Chlorite may be of several generations and often shows fibrous, platy and granular forms in the same specimen.

In specimen D.2713.3 an inclusion (possibly of tuff) has been thermally metamorphosed. Biotite of metamorphic origin, with a marked red-brown colour and excellent sieve structure has resulted. Chalcedonic silica is also present in this specimen. Crystals of a red garnet were observed in hand specimens from station D.2713 but none is present in the thin sections.

At Bald Head the lower part of the sequence is of tuffs and agglomerates varying in thickness, and the lavas of the headland equate rather unsatisfactorily with those across the col. Pyroxene-andesites also occur here and they have proved to be very similar to those observed in the Church Point area. Most of the andesites recorded in both of these areas are highly chloritized and calcified (again no epidote has been observed), but specimens from a flow (D.2772.2) were a little fresher. The groundmass is a devitrified glass and the plagioclase phenocrysts have the usual andesine composition. Two pyroxenes are represented, hypersthene and augite, and both display alteration to biotite and chlorite. Some of the feldspars are sericitized. Silicification has taken place, and an occasional quartz phenocryst is developed. Some of the plagioclase phenocrysts exhibit a complex zoning.

At the Camp Hill promontory there is very little tuff below the lava flow which is contaminated with material from the agglomerate group on which it rests. The distribution of the andesites at Camp Hill and Bald Head is shown in Figs. 4 and 5, respectively.

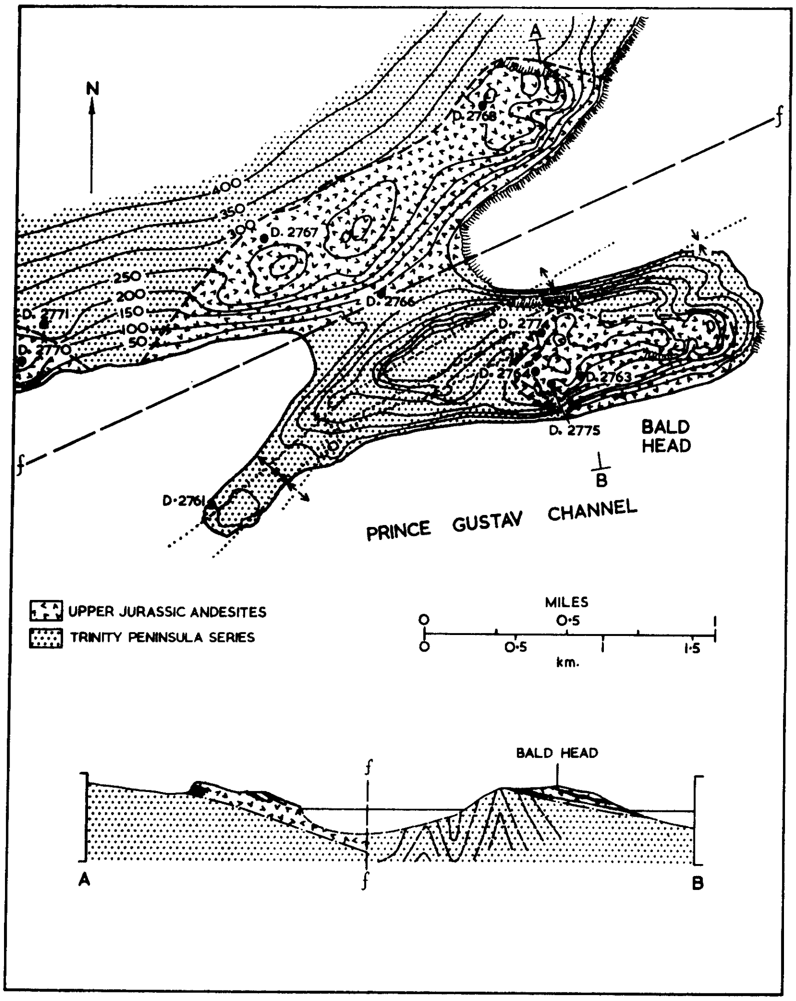

FIGURE 5

Geological sketch map of Bald Head, east coast of Trinity Peninsula. The station positions are shown and the contours are given in feet. The cross-section A—B indicates the general structure of this area.

VII. CRETACEOUS SYSTEM—LOWER TO MIDDLE CAMPANIAN

1. LAGRELIUS POINT CONGLOMERATE

The only exposure of the lowest beds of the Cretaceous in west James Ross Island is in a cliff section 2 miles (3·2 km.) south of Lagrelius Point and extending almost to Matkah Point. These beds are vertical, form high cliffs plunging into the sea and are capped by tuffs and agglomerates of the James Ross Island Volcanic Group. Sections through these beds are, therefore, only available in cracks and gullies formed by drainage from the cliffs above. As these were seldom deep no attempt at a comprehensive section could be made and the boundaries of the beds could not be determined accurately. Their stratigraphic position has been decided on structural considerations.

The beds are coarse conglomerates with very few interbedded grits and sandstones; the conglomerates themselves have a coarse sandy matrix. Their constituents are principally indurated sediments, sandstones, greywackes and mudstones with occasional igneous rocks and some tuffs. The grade size is pebble to cobble. The boulders are orientated with their long axes parallel to the bedding, which is not prominent within the conglomerates but can be determined from the sandstone intercalations. No fossils were found and the thickness of this sub-division is unknown.

2. LOWER KOTICK POINT BEDS

The outcrops immediately south of the exposures of the Lagrelius Point Conglomerate are at Kotick Point. They are very clearly subdivided into two parts, a lower and an upper, which are of quite different lithologies. Outcrops of the lower beds are interrupted on the north by the unconformity with the James Ross Island Volcanic Group, but to the south they continue along the cliffs (their only exposure) for approximately 2·5 miles (4·0 km.). The lower limit of these beds is not known but it has been calculated that they are not more than 1,000–1,500 ft. (305–458 m.) thick. The upper boundary of this sub-division is defined as the terrace halfway up the cliff, because the lithology changes above this point.

The sequence was measured and is given in Table II. The succession starts with dark sandy mudstones and shales, above which are 2 ft. (0·6 m.) of crystalline limestone. The limestone appeared to be conformable both above and below but its lateral boundaries were obscure and it could not be traced in the section on either side. It could be either a nodular development or a limestone boulder, both of which have been recorded previously from these beds. Plant remains and lamellibranchs (D.3018.2–9) were collected from the limestone. Due to the lack of time the necessary intricate cleaning before identification could not be done, but they promise to be very interesting because they are the earliest fossils in the Cretaceous succession and are well preserved.

Above this are horizons of green sandy mudstone, which are similar to the shales in lithology but of lighter colour and without their well-marked cleavage. These are replaced by dark sandy shales with thin intercalations of yellow sandstone. The shales become lighter in colour and show rust-coloured weathering products towards the top. They give way to sandy mudstones and then to a predominantly sandy horizon, which is also mentioned by Stoneley (1953, p. 23). Above this, shales with a few sandy horizons again predominate to the top of the sequence. This section was measured at the northern end of the outcrop. The various beds reach sea-level farther south along the coast, and there is some lateral variation though the main trends persist. Thin conglomerate lenses with bands of grit occur near the main sandy horizon.

In the upper shales, 2·5 miles (4·0 km.) south of Kotick Point, intraformational unconformities with current-bedding are exposed in the low sea cliffs. Casts of gastropods and worms were obtained from a limestone boulder here, but this material has not yet been prepared and identified.

Reference has been made by earlier workers (Stoneley, 1953) to the presence of boulders in this sub-division and black calcareous nodules have also been observed. Stoneley was of the opinion that the boulders were carried out to sea embedded in the roots of trees and were dropped into their present position when they were dislodged. This is a possible explanation but it should be pointed out that there is a distinct paucity of plant material in these beds; it does not become common until the coarser sediments overlying the shales and mudstones are encountered.

Following the deposition of the Lagrelius Point Conglomerate, this area became quiescent and there was a slackening in the rate of sedimentation which was possibly caused by subsidence. The nature of the sediments in the lower part of Kotick Point suggests that there were slightly fluctuating sea-floor conditions some distance from land, but as time progressed turbulent conditions were re-established.

TABLE II

SECTION WITHIN THE LOWER KOTICK POINT BEDS AT KOTICK POINT TO SHOW SEQUENCE AND ROCK TYPE

ft.	in.	m.	*Rock Type*
			Cliff peters out beneath scree slopes
24	0	7·30	Ferruginous sandy shales with thin green sandstone bands
	6	0·15	Yellow sandstone band
11	0	3·35	Ferruginous shales
	8	0·20	Yellow sandstone
37	0	11·27	Ferruginous shales with fine-grained green sandstones
34	0	10·36	Current-bedded green sands interbedded
14	0	4·27	Sandy mudstones
	2	0·05	Ferruginous yellow-stained sandstone
13	8	4·16	Ferruginous shales and mudstones
	4	0·10	Medium-grained sandstone
22	0	6·71	Grey-green sandy mudstones and shales
2	0	0·61	Medium-grained compact yellow sandstone
38	4	11·68	Black sandy shales with flaggy horizons
9	0	2·74	Fine-grained green sandy mudstones
10	0	3·05	*Snow-covered scree*
4	2	1·32	Green sandy mudstone
10	0	3·05	*Snow-covered scree*
2	0	0·61	Crystalline black limestone
18	0	5·49	Mudstones and shales
250	10	76·47	

Whenever the wave base affected the sea floor, intraformational unconformities were formed. The culminative effects of this cycle are obscured by scree.

3. UPPER KOTICK POINT BEDS

These beds crop out over a wide area from Kotick Point southwards as far as the north side of the bay north of Tumbledown Cliffs (Plates IIIc and d). They may also crop out at Rink Point. The best exposures are on the upper part of Kotick Point and in a small valley which trends parallel to the coast about 2·5 miles (4·0 km.) south of Kotick Point. Their distribution is shown in Fig. 6.

The lowest beds exposed are cyclic-bedded sediments, which commence as conglomerates and grade upwards through pebbly sandstones into coarse sandstones at the top of the cycle. Each cycle is about 20 ft. (6·1 m.) thick. Following these are coarse sandy beds, which also exhibit cyclic bedding though to a lesser degree. They contain coal streaks and carbonized plant remains, and vary in lithology from sandy shales with a very irregular parting to sandy flagstones and massive, coarse, current-bedded sandstones,

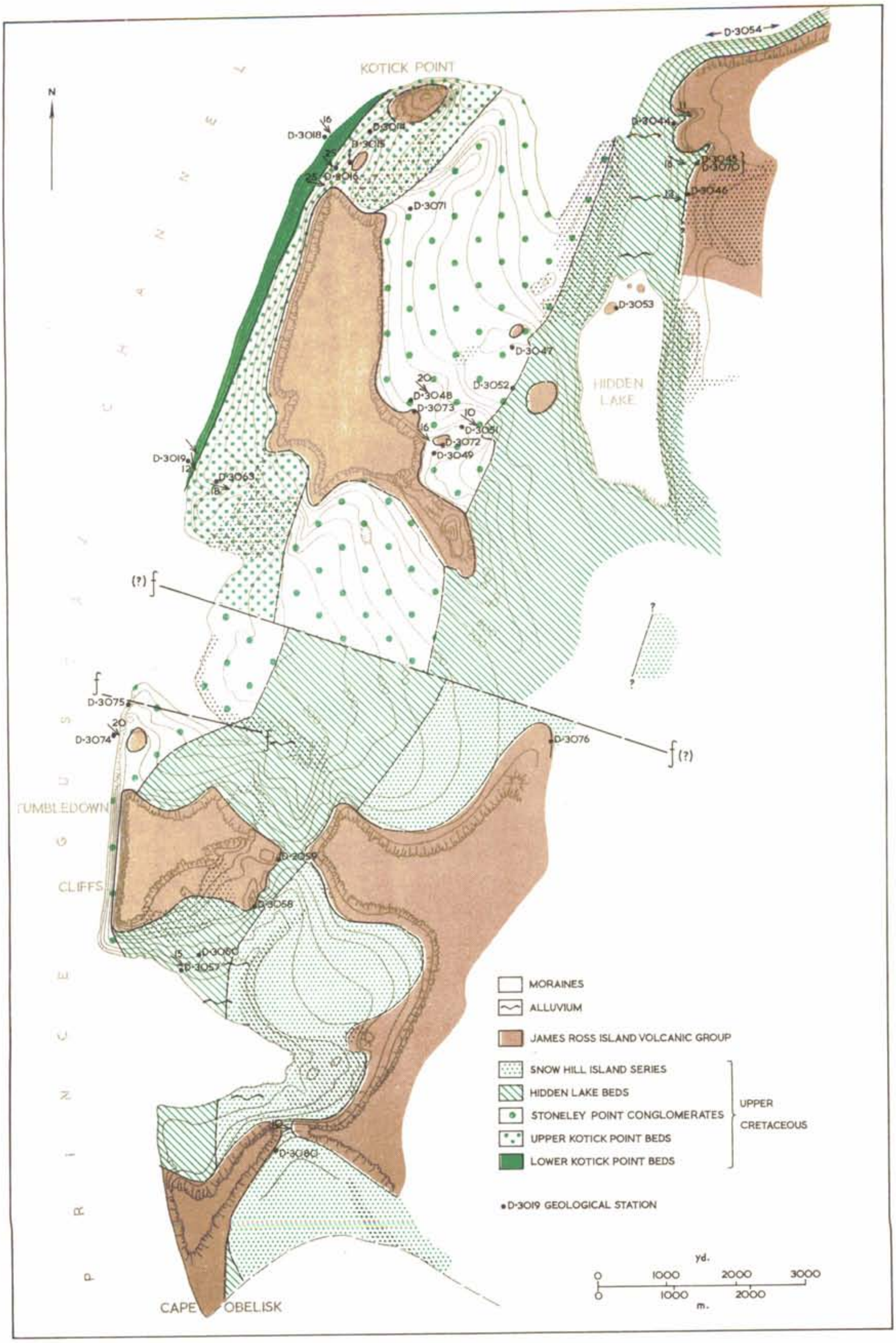

FIGURE 6

Geological map of part of the west coast of James Ross Island between Kotick Point and Cape Obelisk. The station positions are shown and the contours are given in feet.

Conglomerates, which are developed occasionally, cap the main crags on Kotick Point. Variegated, poorly cemented sandstones (Plate IVa) separate them from further thick conglomerates at the top of the ridge, which immediately underlie rocks of the James Ross Island Volcanic Group. The sandstones are sometimes pebbly and, besides well-rounded pebbles of metamorphic rocks, there are numerous fragments of friable shales and sandstones which have not been derived from any great distance.

Peculiar lens-like structures, which are definitely post-formational because they cut across the bedding planes in some instances, are developed in the sandstones (Plate IVb). They may have a concretionary origin. Some of these lenses are only 1 ft. (0·3 m.) wide but 15–20 ft. (4·5–6·1 m.) long, and there is considerable variation in their size. The long axis of each structure is generally roughly parallel to the bedding. A weak jointing has been imposed on the pebbly sandstones, the planes having a variable dip of 28–44° to the north and a strike of 215–284° mag.; in contrast, the beds dip at 25° to the south-east and strike 225° mag.

In the conglomerates which form the highest beds of the cliff a boulder of conglomerate was recorded within the conglomerates, and this is evidently a block of the source rock (Plate IVc). To the north, there are no rock exposures above this horizon as the ground east of the Kotick Point ridge is the site of a former small cirque glacier; the next exposures to the east are of rocks characteristic of the succeeding beds. In the south of this area, too, the outcrops are obscured by morainic material deposited by cirque glaciers.

Conditions in this period were similar to those existing during the deposition of the previous group of beds, except that the rhythm is more pronounced. This is well displayed at the beginning of the period but it gradually becomes less definite until there is a uniform condition throughout. The general trend is towards an increase in coarser deposits, which may denote either the approach of a coastline to the west or renewed uplift of the landmass there. The presence of a conglomerate boulder within the conglomerates (Plate IVc) proves conclusively that the sediments of west James Ross Island were derived by the erosion of another sedimentary sequence of which there is no longer any trace but which was similar in lithology to the present beds. Also, the source could not have been a great distance to the west during at least part of the period.

The lowest ammonoid remains yet found in this succession were obtained from these beds (D.3063). They are fragmentary and have been identified as an indeterminate puzosiinid by Howarth (1966). No other fossils were found despite a prolonged search.

4. STONELEY POINT CONGLOMERATES

These are the first beds which crop out extensively along the west coast of James Ross Island. They occur in the sea cliffs south of Brandy Bay and form the northern part of Tumbledown Cliffs. They also occur to the west of Hidden Lake and are partly overlapped in this area by outcrops of the James Ross Island Volcanic Group at its northern and southern ends. The base of the succession is not exposed, although its position near Hidden Lake is marked by a prominent feature. The top of the group is best exposed in the Tumbledown Cliffs and Brandy Bay areas. A prominent line of crags at Tumbledown Cliffs dwindles away southwards and the beds forming it disappear below sea-level. The conglomeratic nature of the rock changes and a succession of sandstones, and interbedded flags and conglomerates, makes its appearance. The conglomerates thin out and disappear at the southern end of the cliff, where the junction between the Stoneley Point Conglomerates and the overlying Hidden Lake Beds is believed to occur. This is one of the best-graded sub-divisions in the whole of the Cretaceous succession and consequently the boundary is a very arbitrary one.

The rocks comprising these beds are characterized by two main features: the presence of yellow tuff fragments and large blocks of vivid green glauconitic sandstone, shale and mudstone. There is some variation in the exposed sequence at the three main localities, although only two of them were well enough exposed to warrant detailed description. The present description of these beds agrees closely with that of Stoneley (1953).

a. *Exposures between Brandy Bay and Stoneley Point*

The lowest beds of this sequence are exposed at a bend in the coastline, the slightly sinuous nature of the coast giving the beds a false appearance of being folded. The sequence comprises coarse grits, pebbly sandstones and conglomerates 40 ft. (12 m.) thick. The lithology is demonstrated in the following representative section taken over a short distance:

	Thickness	
	(in.)	(cm.)
Dark grey mudstone	4	10·1
Conglomerate with sandstone matrix	4	10·1
Green glauconitic sandstone, shaly at its base	3	7·6
Green-yellow sandstone	7	17·8
Conglomerate with 0·25–1·50 in. (0·6–3·7 cm.) pebbles		
Streaks and lenses of grey-green sandstone	12	30·5
Fine-grained green-yellow sandstone	3	7·6
Dark grey-green sandstone with mudstone pebbles	9	22·9

The conglomerates contain numerous angular fragments of an emerald green shale. Close to the top of these beds there are two yellow-brown weathering bands of flags and massive mudstones, which are similar to two bands capping a similar succession at Tumbledown Cliffs.

The succession passes upward into loosely cemented sandstones, sometimes with fine interbedded shales and coarser conglomeratic bands in which there are tuff, green glauconitic sandstone and mudstone fragments. The conglomerates become much coarser and completely lack orientation in parts. There is an almost indiscernible alternation between the unsorted and very poorly sorted conglomerates, which may be interpreted as graded bedding.

The phenoclasts fall into two groups: those which are rounded and those which are sub-angular. The rounded fragments are derived from metamorphic rocks, tuffs and lavas (?), whereas the sub-angular fragments are mainly sandstones and mudstones.

There is a break in the succession at this point and about 80–100 ft. (24·4–30·5 m.) of sediments are not exposed. The sequence which follows is of indurated sandstones and pebbly sandstones with some conglomeratic bands, passing gradually upward into light and dark grey grits, which are poorly cemented and contain pebbly bands. The glauconitic sandstone and mudstone pebbles are very infrequent at these higher horizons and it is proposed that the top of this sub-division is the line where they cease to be an important constituent of the conglomerates.

Two features of interest regarding the provenance of these rocks emerge from their study. Rhyolitic tuffs, similar to those of the Upper Jurassic Volcanic Group, are present but they are rounded. They occur in conglomerates which also contain angular and much softer sandstone fragments. It is possible that this is convincing evidence pointing to the former presence of a Lower Cretaceous series in the north-east Graham Land area. Stoneley (1953) has referred to a pebble containing a probable *Aucellina andina* as indicative of this. Hence there would be time for the Upper Jurassic tuffs to be rounded prior to their original deposition, and at the same time provide a source for the glauconitic rocks. Their subsequent erosion to form the Upper Cretaceous has not involved them in transport over a great distance and therefore the glauconitic constituents have remained sub-angular.

b. *Exposures in the Tumbledown Cliffs area*

In this area there is a considerable thickness of beds which are not exposed in the Brandy Bay area. At the top of the northernmost cliffs there are two rusty weathering bands mentioned previously in connection with similar bands recorded in the Brandy Bay area. They are very prominent but somewhat thicker here. Because the rest of the succession is similar to that of the Brandy Bay area (if this correlation is carried through), it has been tentatively adopted. The beds below these bands comprise a similar alternation of sandstones, although they are of somewhat finer grade in parts. The conglomeratic layers are also very similar, being unsorted with angular sandstones and the usual assortment of metamorphic rocks. There is less green shale in this part of the sequence, although it is still prominent.

In the higher beds of the cliff there is no exact bed for bed parallel with the Brandy Bay area but there is a lithological resemblance. Conglomerates alternate with sandstones, which are well sorted, medium to coarse, and often not well cemented. Flaggy sandstones are often developed and there is a small amount of shale. Very few remains of palaeontological significance were found. Stoneley (1953,

Table III

SECTION MEASURED WITHIN THE HIDDEN LAKE BEDS AT STATION D.3070, NEAR HIDDEN LAKE

(This section illustrates the degree of variation and the thickness of individual members of the sequence. Most of the beds tend to thin out laterally, hence no detailed correlation with other areas is possible. This type of deposit extends from Cape Lachman to Cape Obelisk and has been described in the text as the Hidden Lake Beds.)

Rock Type	*Thickness*			*Comments*
	ft.	in.	m.	
James Ross Island Volcanic Group agglomerates	+100	0	+30·50	
				Unconformity
Scree	30	0	9·14	
Sandstones and shales	15	0	4·57	All characterized by marked red and yellow weathering products on bedding planes
Green sandy flags	2	0	0·61	
Rubbly sandstones	1	6	0·46	
Yellow-green shales and flags	20	0	6·10	
Coarse quartzitic sandstone	0	7	0·18	Specimen D.3070.1
Pebbly sandstone	0	2	0·05	Pebbles of local derivation; glauconitic sandstones, shale fragments, etc.
				Non-sequence; local only
Fine-grained red-brown flags and shales	+10	0	+3·05	Contorted; hollows infilled with shale fragments and detritus
Scree	20	0	6·10	Small outcrops of medium-grained grey flaggy sandstone and shale enough to indicate general rock type. Marked red-brown weathering
Grey flaggy sandstone	1	4	0·41	Partings ill-defined; weathering red, brown and yellows; indistinct tracks of worms; plant fragments
Buff flags	6	0	1·83	Fine- to medium-grained
Pyritous sandstone and shales	1	10	0·56	Thin flaggy pyritous (1–2 in.; 2·5–5·0 cm.) sandstone bands separated by buff paper shales in 1–2 in. (2·5–5·0 cm.) thick layers
Grey shales and flagstones	12	0	3·66	
Scree	30	0	9·14	
Green shales and sandy flagstones	15	0	4·57	Distinct blue cast on weathering of shale in lower 8 in. (20 cm.); pyritous sandstone in flaggy bands frequent towards top; worm tracks and wood
Green mudstone/shale		6	0·15	Extremely fine-grained, pyritous, liver-weathering colour
Green sandstones and shales	3	3	0·99	Pass down into:
Green flags and shales	3	0	0·91	
Grey flags	2	6	0·76	Cyclic bedding; shale partings
Grey sandstone		4	0·10	Becomes better washed towards top and passes gradually into flags
Clayey mudstone		4	0·10	Numerous worm casts
Coarse green sandstone		9	0·23	
Fine-grained buff flagstone	4	10	1·47	Well-indurated; alternate light and dark banding may be cyclical in origin; 6 in. (15 cm.) from base are ferruginous layers with carbonized wood remains; small oval iron-stained patches occur throughout and generally emanate from a carbonized wood centre; whole group well jointed
Buff flags		9	0·23	Medium-grained
Buff sandstones	1	2	0·36	
Green shales	2	0	0·61	3 sandstone bands at base; lower part buff-weathering; rest green grey; good cleavage in upper part
Buff sandstone	1	0	0·31	Shaly layer at base becomes ill-defined upwards
Grey-green paper shale		9	0·23	
Pyritous sandstone		6	0·15	
Grey shales		3	0·08	
Pyritous sandstone		3	0·08	
Paper shales		9	0·23	Buff weathering
Pyritous sandstones		3	0·08	
Green paper shales		6	0·15	
Grey shales	6	0	1·82	Buff to red weathering; cleavage poorly developed
Fine-grained pyritous sandstone		3	0·08	Extremely prominent horizon; liver-weathering colours; dip 12°E., strike 215°
Green-brown sandy shales	1	0	0·31	Cleavage poorly developed; deeply weathered
Green sandstone and green shales	8	0	2·44	Good cleavage in shales; thin sandstones separate shales; liver-coloured weathering well-developed on bedding planes
Sandstone and shales	8	0	2·44	Rapid alternation of types; buff, blocky weathering sandstones; occasional bands more massive; both separated by buff shales, red and brown weathering common; very colourful
Shales	1	6	0·46	Green weathering
Shales	1	0	0·31	Buff weathering
Flaggy sandstone		10	0·25	
Grey-green shales	1	6	0·46	Certain partings more especially emphasized and give impression of flaggy bands
Coarse sandstone	1	5	0·44	Occasional medium-grained bands
Scree	75	0	22·86	Small shale/sandstone outcrops; some of latter show extensive worm casts; light grey sandstones especially prominent in top 20 ft. (6·1 m.)
Green shales	2	0	0·61	Well-indurated; good cleavage parallel to bedding planes
Coarse green sandstones and flags	13	0	3·96	Flaggy partings; poorly exposed; unidentifiable shell fragments at top
Mudstone		6	0·15	Blocky weathering; liver-coloured weathering products
Coarse green sandstone		2	0·05	
Brown paper shales		3	0·08	Rusty weathering
Coarse green sandstone	4	0	1·22	Occasional thin green glauconitic clay partings
Green sandstone with pebbles		6	0·15	Pebbles principally of glauconitic clays
Green and yellow flaggy sandstone	8	0	2·44	
Green flags and shales	3	3	0·99	Flags fine; shales coarsely laminated
Green flaggy sandstone	1	10	0·56	Occasional pebbles
Green shale		6	0·15	Considerable number of worm casts
Grey sandstone		8	0·20	Medium-grained
Sandstone	1	1	0·34	Rusty weathering
Scree	18	0	5·49	Sandstones with worm casts and wood fragments
Green and yellow flagstones	6	0	1·83	Vary in thickness and degree of perfection of partings; wood fragments
Coarse pebbly sandstone		4	0·10	Pebbles of green glauconitic mudstone in bright green glauconite; finer towards top
Green sandstones	1	0	0·31	Medium- to coarse-grained; ill-defined graded bedding; at 6 in. (15 cm.) a 2 in. (5 cm.) band of green mudstone or fine sandstone
Yellow shales	1	6	0·46	Ill-developed partings; occasional 1–2 in. (2·5–5·0 cm.) bands of yellow sandstone
Grey-green sandstone	1	4	0·41	
	Base not seen			
	357	6	109·02	

p. 27–31) was more successful, finding over 200 specimens of Foraminifera in rocks from the southern end (the higher horizons) of this sequence (Macfadyen, 1966).

Shallow-water conditions existed at the start of this period and as time progressed the shoreline retreated. The instability of the area can be judged from the rapid alternation of sediments but there were no violent changes in the environmental conditions.

The thickness of this group of beds is about 1,100 ft. (335 m.) and it is probably slightly thicker in the south than in the north. It seems preferable to correlate the beds of the Tumbledown Cliffs area with those of the Brandy Bay–Stoneley Point area, rather than equating the latter with those exposed at Kotick Point, as has been done by other workers. This is based partly on projection downwards from a plane established on palaeontological concepts in the group of beds above these, and partly to avoid theorizing on the nature of beds which cannot be seen at either locality (Stoneley, 1953, p. 28).

5. Hidden Lake Beds

These beds are well exposed in all five areas where they occur. They are the most fossiliferous beds so far encountered in the stratigraphic column. In the north of James Ross Island, north of Bibby Point, their relationships with other rock groups are interesting. They also crop out between Brandy Bay and Stoneley Point, and again on the north-eastern side of the bay between Stoneley Point and Rink Point. They are encountered to the north-east of Hidden Lake and their last exposure is on the north coast of the bay immediately north of Cape Obelisk (Fig. 6). Fossil remains have been found at every locality but at the last-named there is ammonite evidence for the age of these beds.

The sequence at the Hidden Lake locality was measured in the central gully of the three which occur there. The total thickness was found to be 357 ft. (109 m.) and the principal features are given in Table III. In all localities a very similar lithology was recorded, although nowhere was any correspondence in actual sequence noted. (Detailed measurement was not carried out in other areas.) The individual units are thin, often only a matter of inches, and the differences in resistance to erosion within them is marked. The topographic features caused by erosion of the rocks are generally of a dip slope and scarp nature, which is exceptionally well developed at Brandy Bay.

The lowest beds in this sequence are sandstones and flagstones which crop out on the north coast of the bay north of Cape Obelisk and on the north-east coast of the bay between Rink and Stoneley Points. They have not been productive palaeontologically and are transition beds between the sandstones and conglomerates of the Stoneley Point beds and the sandstones developed in the upper part of the Hidden Lake Beds. Similar rocks occur in a deep gully north of Bibby Point and these are thought to be of the same age. A prolonged search of these beds may reveal fossil remains, as the uppermost sandstones contain indistinct impressions of *Inoceramus*. They are composed of flaggy and massive glauconitic sandstones with some conglomerates, which become rare towards the top of the sequence; none are represented in the section studied at Hidden Lake.

The base of the Hidden Lake section is composed mainly of sandstones, both massive and flaggy, with occasional fine shale bands. Many of the sandstones are shaly. Towards the middle and top of the sequence shales become increasingly important and the sandstones become thinner. Thick sandstones with shale intercalations and a disconformity occur at the top of the sequence below the unconformity with the James Ross Island Volcanic Group.

In the Bibby Point area, especially just below the col separating the main Bibby Point ridge from Lachman Crags, the transition between the Hidden Lake Beds and the Snow Hill Island Series is exposed. These beds are most variable but they are of an extremely interesting nature. Loose sands develop and the shales disappear completely. The massive sandstones and flagstones persist but they only recur at greater and greater intervals. Concretions become common and they often assume peculiar forms. A cylindrical form is very common, as are the rounded varieties. Sometimes several of these forms are fused together. A persistent pisolitic band can be traced across the area but this has not been found elsewhere. Considerable amounts of iron staining are present in the loose sands, sometimes in patches but generally along the line of a fissure. These rocks give the impression that they are a shoreline facies but neither current-bedding nor ripple-marks have been detected. The upper boundary of the Hidden Lake Beds is presumed to lie just below the col.

On the south side of Brandy Bay the same kind of transition is observed, and the boundary is assumed to pass across the coastline approximately halfway to the mouth of the bay.

A great many examples of the lamellibranch, *Inoceramus*, are preserved as impressions on the surface of sandstones at a number of localities on the north shore of the bay north of Cape Obelisk. This horizon can be traced northwards in the sequence and *Inoceramus* has also been recorded from Hidden Lake, from the bay between Rink Point and Stoneley Point, from the beds on the southern shore of Brandy Bay and from beds north of Bibby Point. It is not as abundant at all these localities as it is near Cape Obelisk but, apart from a specimen recorded by Stoneley (1953) from the beds of the Tumbledown Cliffs area relatively close stratigraphically to this occurrence, *Inoceramus* has not been recorded elsewhere in this succession. Besides noting the occurrence of *Inoceramus*, Standring (1956, p. 10) also recorded three specimens of desmoceratid ammonites, which have since been identified by Howarth (1958, p. 9) as *Desmophyllites* sp. indet. and *Tetragonites* (*Saghalinites*) cf. *cala*. The writer collected a well-preserved ammonite from this locality and this has been identified by Howarth (1966) as *Submortoniceras chicoense*. All these specimens indicate a Campanian age for the sediments. No other specimens of value were found despite a prolonged search.

An ammonoid found in the outcrops at Hidden Lake has been identified as *Perisphinctes* sp. (Spath, 1953). This is an Upper Jurassic form, and its state of preservation gives rise to the belief that it was derived from earlier sediments.

The outcrops on the north-east coast of the bay between Rink Point and Stoneley Point have produced several poor impressions of *Inoceramus* and some ill-preserved gastropods. *Inoceramus* is again present as impressions in the sandstone beds directly below the col to the east of Stoneley Point.

Very few fossils were found in the Brandy Bay area. Stoneley (1953) reported the presence of the lamellibranch, *Isognomon*, and carbonized plant remains, while the writer found impressions of *Inoceramus* in sandstones on the south-west side of Brandy Bay.

Besides wood, which was mainly carbonized, the only fossil remains found to the north of Bibby Point were poorly preserved *Inoceramus* impressions.

The stratigraphic horizon determined by the occurrence of *Inoceramus* in the Cretaceous sediments of north-west James Ross Island is the best that can be found in the lower part of the Cretaceous strata. Its limitations must be realized, not least that the presence of *Inoceramus* may be governed by the physical conditions existing at the time, i.e. that it may be a diachronous horizon. It occurs both in the beds below and above the Hidden Lake Beds, but to a more limited extent. This evidence has been used as a basis for establishing a stratigraphic sequence in the lower part of the Cretaceous of north-west James Ross Island.

The conditions of deposition were fairly obviously shallow water, and the chemical activity that gives rise to the pisolitic and concretionary horizons would point to a warm climate with occasional desiccation towards the close of the period. A general uplift throughout this period must therefore be assumed, or possibly a cessation of movement and the change caused by silting up of the area. The thickness of these beds, approximately 1,100 ft. (335 m.), appears to be constant throughout the length of James Ross Island.

6. SNOW HILL ISLAND SERIES

These beds are an upward continuation of the sequence without any discernible break and they occur to the east of Brandy Bay and at Cape Obelisk (Plate IIb) on the west coast of James Ross Island. They were examined closely by Croft in the Lachman Crags area on the west coast of Herbert Sound; they also occur at The Naze, Ula Point, Rabot Point (?) and Hamilton Point on James Ross Island, on Snow Hill, Seymour, Cockburn and Humps Islands, and they have been found at False Island Point and Cape Lamb on Vega Island.

It is extremely difficult, if not impossible, to subdivide these sediments on lithological grounds, as was done for the underlying strata. For the most part they are uncemented sands and gravels with intercalated sandy clays and clays, often of a dark red-brown colour but frequently green. There are horizons of nodules, which are mainly of a medium-grained glauconitic sandstone with a calcareous cement. In certain areas, e.g. The Naze and Cape Lamb, almost every nodule contains a fossil, but in others the nodules are either barren or absent altogether. Although these structureless sands have yielded a good fauna, their interrelationships are not clear and the succession has been subdivided arbitrarily on a geographical basis. A considerable amount of work remains to be done on the ammonite fauna, particularly with regard to its interrelationships.

The outcrops at Lachman Crags, Cape Lamb, Ula Point, Rabot Point and Hamilton Point have been examined carefully and brief visits were paid to Humps and Snow Hill Islands. A feature common to the beds of all these localities is the presence of the serpulid, *Rotularia* (Ball, 1960), which is only rarely present at Lachman Crags and Cape Lamb but which becomes common at The Naze. It is not prominent at Humps Island but it is found in great numbers at Ula Point and on Snow Hill and Seymour Islands. There is no evidence relating to its incidence at Seymour Island but only one species has been found, and it can be assumed that it is not as common as at Snow Hill Island.

The further sub-division of the Snow Hill Island Series, which is the thickest of the sub-divisions of the Cretaceous proposed in this report, totalling about 11,750 ft. (3,580 m.), is not easy. Fossil collections have been made by the geologists of Operation Tabarin, and by Croft, Stoneley and Standring of the Falkland Islands Dependencies Survey. The ammonites from these collections have been described by Spath (1953) and Howarth (1958), both of whom have commented on the paucity of stratigraphic data. This information is difficult to provide for these beds, because their attitude can only be inferred from the underlying sediments and from occasional sandstone bands within this sub-division. A geographical sub-division based on the observed continuation of the constant easterly dip has been adopted. An exception to this is the outcrop at Humps Island which is discussed on p. 34.

7. DISCUSSION OF THE SNOW HILL ISLAND SERIES

a. *Lachman Crags*

The beds directly overlying the Hidden Lake Beds are light green- or yellow-coloured sands with numerous soft sandy concretions, rarely containing macro-fossils; a search for micro-fossils has not been carried out. Fossil remains are not frequent in these lowest beds, although they become more so higher in the succession. A good specimen of *Eupachydiscus grossouvrei* was obtained from the col near Bibby Point, and also a specimen of *Baculites*. Croft collected a good ammonoid fauna from beds a little higher in the succession at localities on the west coast of Herbert Sound and they have been identified by Spath (1953) as follows:

Gunnarites kalika
Gunnarites rotundus
Gunnarites paucinodatus
Maorites densicostatus
Maorites pseudobhavani
Maorites seymourianus
Maorites sp. aff. *suturalis*
Maorites (?) sp. ind.
Gaudryceras (*Neogaudryceras*) *pictum*
Gaudryceras sp.
Tetragonites (*Saghalinites*) cf. *cala*
Pseudophyllites peregrinus
Neograhamites taylori
Hoploscaphites quiriquinensis
Oxybeloceras aff. *mortoni*
Polyptychoceras sp.
Parapuzosia (?) sp.
Phylloptychoceras zelandicum
Baculites aff. *rectus*
Oiophyllites decipiens
Patagiosites aff. *amarus*
Eupachydiscus grossouvrei

The specimens collected from Brandy Bay are included in this list. This collection is one of the most comprehensive yet obtained from a faunal locality on James Ross Island.

The Lamellibranchia, which have not yet been worked on in detail but which have been identified by the late Dr. L. R. Cox, are represented by the following:

Neilo sp.
Cucullaea (?) sp.
Cucullaea grahamensis
Lahillia luisa
Eriphyla (?) sp.
Eriphyla cf. *meridiana*
Nordenskjöldia nordenskjöldi
Nucula sp.
Nucula sp. (? *N. stationis*)
Nucula suboblonga
Nuculana (?) sp.
Mytilus sp.
Astarte (?) sp.
Turnus (?) sp.
Entolium orbiculare
Laevitrigonia regina
Laevitrigonia aff. *regina*
Laevitrigonia sp.
Pterotrigonia cf. *pseudocundata*
Oistotrigonia antarctica
Callistina sp.
Modiolus (?) sp.
Thracia (?) sp.
Inoceramus sp.
Lucina or *Fimbria* sp.
Malletia sp.
Phacoides scotti

Three species of serpulid have been recorded (Ball, 1960): *Rotularia shackletoni*, *Rotularia callosa* and *Ditrupa varicosa*.

The rocks exposed near Lachman Crags are grey or yellow, buff- and brown-weathering sandy clays with occasional clay layers. Within these clays there are occasional flaggy grey-green sandstone and nodular limestone bands, usually less than 1 ft. (30·5 cm.) in thickness. Occasionally the sandstones may be pebbly, with rounded vein quartz and greywacke pebbles predominating. Some of the sandstones are rich in broken shell remains.

The importance of these beds is that they form the base of the Snow Hill Island Series, and this can be proved in the field. This is also the largest fauna recorded from any one locality, with the exception of the collection made at Snow Hill Island by the Swedish South Polar Expedition. Approximately 3,500 ft. (1,065 m.) of these beds are exposed but a further 4,000 ft. (1,220 m.) are concealed between Cape Lachman and the Cape Lamb area. These thicknesses are calculated from an assumed regional dip of 5° in a south-east direction which agrees closely with the measured dips at most of the outcrops along this coast section.

b. *Cape Lamb*

At Cape Lamb there are beds with a very similar lithology to those of Lachman Crags. The principal difference is in the constitution of the nodules in these beds. They are finer-grained, harder and blacker than those recorded in the Brandy Bay and Lachman Crags areas. Moreover, they are the main source of the fauna, because almost all of them possess a fossil as a central core.

The ammonoid fauna, identified by Howarth (1966) from specimens collected over a two-day period, is as follows:

Gunnarites kalika
Gunnarites antarcticus
Gunnarites sp.
Grossouvrites gemmatus
Maorites densicostatus
Maorites seymourianus
Maorites sp.
Kitchinites darwini

That only four genera are represented may be a reflection upon the intensity of collection, which was only carried out near the southern tip of the cape. Beds which have not yet been investigated lie farther to the north. There are, however, strong affinities with the underlying Lachman Crags beds and with the overlying beds of The Naze. Three ammonites not recorded by Spath from Lachman Crags make their appearance: *Gunnarites antarcticus*, *Grossouvrites gemmatus* and *Kitchinites darwini*. The lower localities yielded *Kitchinites*, *Maorites* and *Grossouvrites* (the latter two are also associated on Seymour Island), but the higher localities yielded *Gunnarites antarcticus*. The increase in numbers of *Gunnarites antarcticus* is quite sudden in the upper strata of Cape Lamb. This could be explained by the development of suitable ecological conditions for their increase or to conditions becoming more favourable for their preservation. The latter does not seem likely, since there is little apparent difference between the upper and lower beds at Cape Lamb and nodules of the same type, but which are unfossiliferous, occur in the lower localities.

The link with the beds below those of Cape Lamb is reinforced by the inclusion of *Maorites densicostatus* in the Lachman Crags faunal list. Spath (1953, p. 44–45) does not mention this species in his faunal lists for the area, yet on p. 24 he records *Maorites densicostatus* (C.41349) from Lachman Crags south. It is a common species in the lower beds at Cape Lamb but infrequent in the upper ones.

The following lamellibranchs are well represented throughout these beds:

Barbatia sp.
Cucullaea sp.
Lima (*Limatula*) *antarctica*
Astarte sp.
Arctica sp.
Panopaea sp.
Cytherea antarctica
Pinna sp.
Trigonia sp.
Thracia sp.

This material has not yet been studied in detail.

Only two poorly preserved rotularids were seen. The nautiloid, *Eutrephoceras*, is common both as well-preserved specimens and as individual air chambers. Lobster remains, identified by Dr. H. W. Ball as *Hoploparia stokesi*, were also present. The nodules very probably contain micro-fossils but no investigation of them has been carried out. One or two large bryozoan (?) colonies were collected and an unidentified simple coral was also found.

c. *Dagger Peak and The Naze*

The ammonite fauna of Dagger Peak demonstrates the sudden increase in the numbers of *Gunnarites antarcticus* referred to above and it is represented by 67 specimens. The following genera and species have been recorded:

Gunnarites kalika
Gunnarites antarcticus
Gunnarites bhavaniformis
Gunnarites gunnari
Diplomoceras lambi
Jacobites crofti
Maorites densicostatus
Pseudophyllites peregrinus
Eupachydiscus grossouvrei
Neophylloceras meridianum

The Dagger Peak col locality yielded Croft the following lamellibranch species:

Cucullaea sp. (or *Grammatodon* sp.)
"*Trigonia*" sp.
Thracia (?) sp.
Entolium orbiculare
Pholadomya sp.
Astarte (?) sp.
Laevitrigonia (?) sp.
Laevitrigonia regina
Callistina (?) sp.
Limatula (?) sp.
Lima (*Plagiostoma*) sp.
Eriphyla (?) sp.
Eriphyla cf. *meridiana*
Pinna anderssoni
Pycnodonte vesicularis
Modiolus sp.
Panopaea clausa
Lucina sp.
Nordenskjöldia nordenskjöldi
Oistotrigonia antarctica (?)

The nautiloid, *Eutrephoceras simile*, and the decapods, *Hoploparia stokesi* and *Meyeria crofti*, also occur here. Cirripedes, corals, fish vertebrae, shark's teeth and Bryozoa have been recorded from this locality.

Lithologically the beds consist of light and dark grey (sometimes yellowish) buff-weathering sandy clays and loose uncemented sandstones. The clays are particularly rich in dark grey nodules, which may be either scattered or concentrated into bands, some associated with hard green sandstones rich in glauconite. These may be up to 2 ft. (0·6 m.) thick but they are usually less than 6 in. (15 cm.). Around Dagger Peak the sediments have suffered thermal metamorphism 5 to 10 ft. (1·5 to 3·0 m.) from the igneous mass. Elsewhere the sediments appear to have been little altered by the overlying lavas and tuffs.

d. *Humps Island*

The next outcrops of the Snow Hill Island Series to the east are those exposed on Humps Island where both *Rotularia callosa* and *Rotularia dorsolaevis* have been recorded (Ball, 1960). Lithologically, these beds are loose sands and sandy clays similar to those at The Naze but nodules occur less frequently in them. In the lower parts of the cliffs, however, sandstone bands are quite well represented. At the time this area was worked there was thick snow cover, but Croft's dip measurement (5° to the west with a strike in a direction 358° mag.) was confirmed. The ammonoid fauna collected by Croft from this area is as follows:

Neophylloceras hetonaiense
Phyllopachyceras forbesianum
Pseudophyllites peregrinus
Gaudryceras (*Neogaudryceras*) *pictum*
Tetragonites (*Saghalinites*) *cala*
Gunnarites kalika
Gunnarites flexuosus
Gunnarites pachys
Neograhamites taylori
Neograhamites kiliani

Of *Gunnarites flexuosus* and *Gunnarites pachys* Spath (1953, p. 44) has stated "[they] . . . would be taken by most palaeontologists to be more specialized members of the *antarcticus* stock, rather than more primitive types . . .". He has suggested that the Humps Island beds are immediately post-*antarcticus* in age. If this is so, and the dips recorded at Humps Island are true dips, then according to Spath the maximum thickness of the beds containing *Gunnarites antarcticus* would only be 500 ft. (152 m.). In view of the considerable area over which beds containing *Gunnarites antarcticus* are found, this thickness is considered to be unlikely. It could only be so if the beds were horizontal and this is not the case at the majority of the stations visited. Until further evidence is presented, it is considered preferable on structural grounds that the Humps Island beds should be assigned to a lower position in the stratigraphical succession than those at The Naze or at Cape Lamb. They are, therefore, linked with the Lachman Crags beds to which their fauna is related, but they probably belong to a higher horizon than the Lachman Crags beds and are close to the base of the beds exposed at Cape Lamb.

The lamellibranchs from Humps Island comprise only two genera: *Oistotrigonia antarctica* and *Limnopsis antarctica*.

A large amount of fossil wood is present, as is also the case in many of the outcrops of the Snow Hill Island Series.

e. *Snow Hill Island*

The lithology of the beds of Snow Hill Island has been described by Stoneley (1953) and therefore it was not examined in further detail. The Swedish South Polar Expedition made a comprehensive collection of ammonites, which has been described by Kilian and Reboul (1909). More recently, Spath (1953) has reviewed their work and described material collected by the Falkland Islands Dependencies Survey. In this work Spath included the Snow Hill Island ammonite fauna with that of Dagger Peak and The Naze, but here it is listed separately.

- *Maorites* (?) sp. juv. ind.
- *Tetragonites* (*Saghalinites*) *cala*
- *Jacobites anderssoni*
- *Jacobites crofti*
- *Gunnarites antarcticus*
- *Gunnarites kalika*

Lamellibranchs and gastropods collected by the Swedish South Polar Expedition have been described by Wilckens (1910), but as yet there is no available information on material collected by the Falkland Islands Dependencies Survey. *Rotularia callosa* is the only serpulid described so far (Ball, 1960).

f. *Seymour Island*

The beds on Seymour Island were not visited, but many specimens of *Maorites tuberculatus* have been described from the island by Howarth (1958). *Grossouvrites gemmatus* has also been recorded but there is little else. Interesting results would possibly be obtained by comparing these beds in detail with those of Cape Lamb.

g. *Other areas*

The Snow Hill Island Series crops out at Ula Point, north of Cape Gage, where *Gunnarites antarcticus* and *Jacobites crofti* have been reported along with the serpulid *Rotularia callosa*.

At Cockburn Island *Gunnarites antarcticus* and three genera of lamellibranch, *Pinna* sp., *Pecten* sp. and *Lahillia* sp., were found.

At False Island Point, Vega Island, *Gunnarites bhavaniformis* was found.

Spath (1953, p. 26) has identified a fragmentary impression of a *Maorites* from Persson Island. From structural considerations the beds of this locality should contain the *Maorites* fauna.

The beds at Longing Gap consist of shales and shaly mudstones, and are highly coloured in shades of red-brown and green. Several specimens of *Perisphinctes* were recorded; they are impressions in the shales and are not well preserved. This would point to a Jurassic age for these beds.

VIII. UNCONFORMITY BETWEEN THE LOWER TO MIDDLE CAMPANIAN SERIES AND THE JAMES ROSS ISLAND VOLCANIC GROUP

In general the rocks belonging to the James Ross Island Volcanic Group are outside the scope of this report. However, a detailed study of the unconformity separating them from the Cretaceous rocks beneath (Fig. 7) necessitated an examination of some of them and it seems desirable that they should be described briefly in order that the nature of the unconformity can be clarified.

There are two localities which proved to have special significance: the Hidden Lake area and an area between Cape Lachman and Bibby Point.

1. Marine Tuffs at Hidden Lake

On the west side of Hidden Lake, at an altitude of approximately 1,000 ft. (305 m.), a variation of an unusual nature in the James Ross Island Volcanic Group tuffs was found. This consists of a sequence of chocolate-brown tuffs dipping southwards off a ridge of Cretaceous sediments (Plates IVd and Va). They were of different lithology to any tuffs observed elsewhere, and extremely well-developed current-bedding and ripple-marks were found. This locality was examined closely as there appeared a likelihood

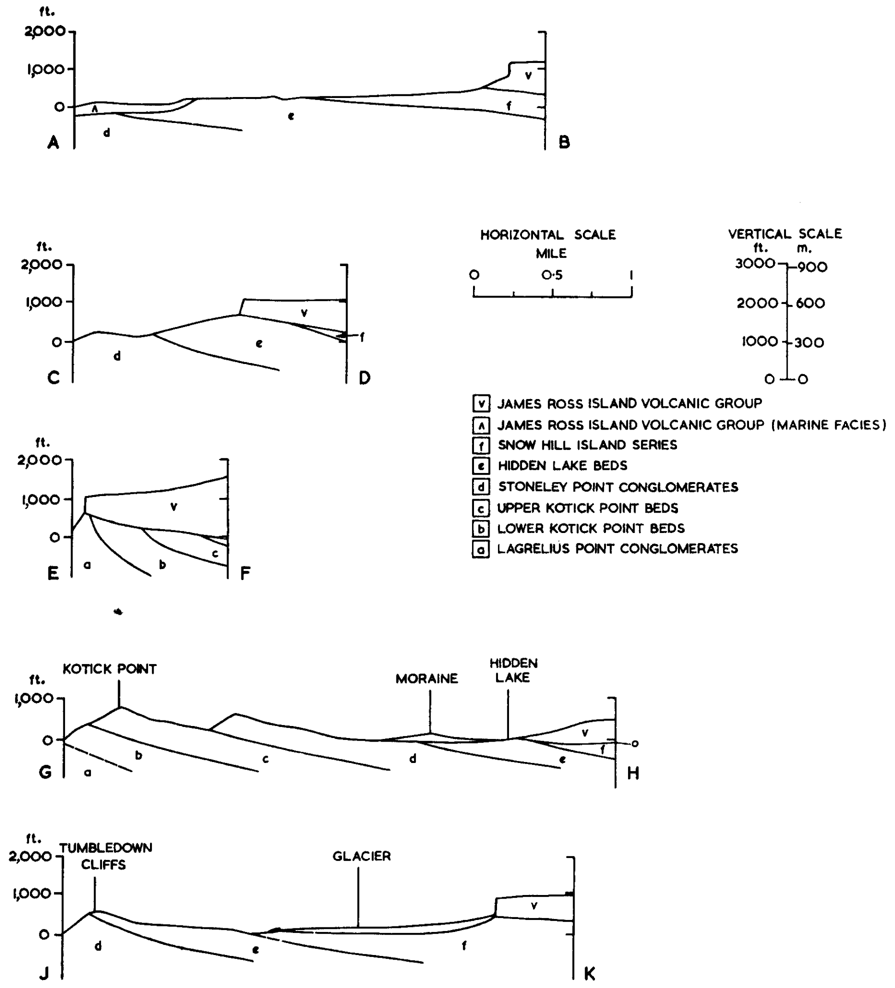

FIGURE 7

Representative sections (A—B, C—D, E—F, G—H, J—K; see Fig. 1) across the west coast of James Ross Island, illustrating the Cretaceous stratigraphic succession, the structure and the nature of the pre-James Ross Island Volcanic Group land surface.

of the beds proving fossiliferous; the search was rewarded by the discovery of 20 to 30 impressions of ophiuroids on a large slab of fine-grained sandstone. A number of these were collected but unfortunately they were so fragile that only two specimens survived the journey back to the Hope Bay station. At another locality 200 yd. (183 m.) away another ophiuroid was discovered. Although the ophiuroids are not identifiable, they prove beyond doubt that these sediments are marine in origin.

The fossiliferous beds rest with angular unconformity upon the Cretaceous and they are only a thin development at the base of the coarse agglomerates forming the main crags to the west. They serve to demonstrate that even the highest beds of the James Ross Island Volcanic Group could possibly be marine in origin and that this area must have been almost entirely submerged at the time of their deposition. There was little, if any, re-worked material present that could have been derived from the Cretaceous rocks beneath. The very fine material was probably airborne dust from distant explosions or it could have been re-worked volcanic material that was lying on the surface at the time this area was submerged.

2. CONGLOMERATE AT BIBBY POINT

A second important section was observed almost at sea-level north of Bibby Point (D.3021). Here, beds of the James Ross Island Volcanic Group rest with angular unconformity on the scarp face of a feature formed by a group of glauconitic sandstones in the Cretaceous (Plates Ic and IIc). These rocks crop out in three or four small crags where they are seen to be coarse ill-sorted conglomerates with a matrix composed of Cretaceous sands and volcanic detritus. The phenoclasts vary from sub-angular to sub-rounded and are principally lavas of the James Ross Island Volcanic Group. There were, however, several boulders of a coarse-grained igneous (probably plutonic) rock (D.3021.2), forming only about 5 per cent of the rocks and of two types. Specimens representative of each type have been studied in thin section.

a. *Porphyritic hornblende-biotite-granite*

This rock is severely weathered, and contains quartz, highly sericitized orthoclase, plagioclase, a strongly pleochroic and twinned hornblende and some biotite.

b. *Porphyritic biotite-granite*

This rock, which is pink in colour, is similar to those observed near Mount Reece on Trinity Peninsula. The mineralogy is simple and the rock is composed mainly of orthoclase, albite and quartz with biotite. Streaks and granules of chlorite are present and nearly all the feldspars are sericitized. The texture of parts of the rock and the intergrowth of individual crystals suggest that the rock has been metamorphosed. The nature of the biotite also suggests metamorphism.

The occurrence of these rocks here excites comment, since rocks of similar type are unknown on James Ross Island and their nearest known outcrop is in the vicinity of Mount Reece on Trinity Peninsula. If they came from there, they must have been transported across the present site of Prince Gustav Channel, but by what means and at what time?

The generally accepted age of the plutonic rocks of the mainland Andean Intrusive Suite is late Cretaceous but pre-Lower Miocene. In order to be present in the basal rocks of the James Ross Island Volcanic Group they must not only have been intruded in pre-Miocene times but a sufficiently long time before to allow for the erosion of the covering rocks and part of the intrusion.

Small fragments of plutonic rock were also seen just above the unconformity near Rabot Point on the east coast of James Ross Island.

The most likely mode of transport is by water, since the boulders had probably been eroded in this way. These specimens may indicate that whilst deposition in the early Tertiary was proceeding on the site of James Ross Island material was coming in from the mainland of Graham Land to the west. Rivers were finding their way across the Cretaceous and Jurassic foothills in both the north and south of this area to a sea which lay somewhere in the vicinity of James Ross Island. There is ample scope for studies on the provenance of the Tertiary sediments using this as a working hypothesis.

The beds at Bibby Point could therefore be a mixed deposit formed at the beginning of the volcanic period when subsidence was still in progress and a large part of the landscape was flooded. This would account adequately for the presence of sediments from the mainland, and Cretaceous shales and volcanic detritus, in the same beds. It would also account for much that is otherwise unexplained in the pre-volcanic landscape of James Ross Island.

3. Pillow Lavas

Further evidence for the aqueous environment at the commencement of deposition of the James Ross Island Volcanic Group is provided by sections which were examined near Cape Lachman (D.3020; Plate Vb), in a crag 750 ft. (228 m.) a.s.l. south of Hidden Lake (D.3076) and in the cliffs south of Lagrelius Point (D.3043; Plate Vc). Pillow lavas are present at these localities; the best and most easily accessible outcrops are those at sea-level near Cape Lachman.

In low sea cliffs on the neck of land connecting Cape Lachman with Lachman Crags there are some well-exposed kidney-shaped pillows (Plate Vb). Their field relations to the underlying and overlying rocks are not clear but they appear to be more associated with the conglomerates described above rather than with the tuffs of Cape Lachman and Lachman Crags.

Specimens were collected from the centre of a particularly large-sized pillow (D.3020.1), from a zone with marked radial jointing which extended from this (D.3020.2) and from an outer vesicular zone (D.3020.3).

The plagioclase feldspars in specimen D.3020.1 form a felted matrix of laths and have a composition of $Ab_{42}An_{58}$ (labradorite). The phenocrysts in the rock are mainly olivine, which is slightly altered along cracks and at the margins. Augite with a strong red-brown colour and slight pleochroism is prominent as laths and granules in the matrix, and there is a considerable amount of ilmenite and leucoxene.

In the thin section from the zone of radiating joints there are considerable changes. Glass becomes more prominent, the small augite laths and granules disappear from the matrix and titanaugite makes its appearance. Leucoxene is present but there is very little ilmenite. The plagioclase becomes more variable in composition but this is difficult to determine precisely, because the laths are thin and often show no twinning. The most marked feature is the presence of small zeolite-filled cavities, containing natrolite and prehnite.

Specimen D.3020.3 from the outer zone shows more prominent vesicles containing natrolite in acicular and radiating forms. There is a noticeable reduction in the amount of olivine and there is more augite in the groundmass. The amount of glass increases and this bears a relation to the zeolites.

At a locality south of Hidden Lake (D.3076) further examples of pillow lavas were found. These have a similar composition to those already described, except that the reactions have been more intense. Calcareous tufa and quartz are associated with the pillow lavas. The zeolites are similar to those in the rock near Cape Lachman but the ones with a radiating structure are better developed. There appears to have been a strong secondary reaction in the centre of the pillow from which the specimens were collected. The relationships in the outer zones are more normal.

From the field relationships and brief petrographic study of these rocks, it is assumed that the basalts having pillow form south of Hidden Lake more nearly approach spilites in composition.

The unconformity between the Cretaceous and the James Ross Island Volcanic Group ranks with Prince Gustav Channel as one of the major geological features of this area. At the end of the Cretaceous period severe tectonic movements occurred, resulting in the main Andean uplift, the principal movements of the faults of Prince Gustav Channel, faulting of the Cretaceous rocks and a general uplift of the James Ross Island crustal block. Following this there was a period of quiescence when the rocks were eroded. Trinity Peninsula was a mountain chain from which streams drained eastwards to a sea occupying the position of the present Weddell Sea.

The resulting topography was mature, with a dissected foreland of softer Cretaceous rocks and hills rising to 600–700 ft. (183–213 m.) at the site of the present west James Ross Island but sloping gently eastwards. The basis of the present landscape was developed at that time, since the present physiography is in many ways a direct reflection of the pre-volcanic land surface. Herbert Sound probably represents the course of an ancient river, and there may have been another originating from the present site of Sjögren Glacier, draining across the south of James Ross Island and depositing the pebbles of plutonic rocks seen near Rabot Point. Continued subsidence probably caused flooding of parts of this area at the beginning of the volcanic episode, and the products of this were deposited on an archipelago off the east shore of Trinity Peninsula. Some of the lavas included material from the Cretaceous within them (Plate IIb). Continued subsidence throughout this period of deposition allowed the accumulation of a great thickness of marine volcanic rocks over this archipelago, whilst they were hardly represented on the mainland. It also allows for the formation of shoreline facies at different heights in the stratigraphic column as the seas advanced over the islands.

The unconformity is therefore of a very unusual nature. It is an irregular surface formed by subaerial erosion, upon which water-laid tuffs, agglomerates and lava flows were deposited without much perceptible planing of the land surface by marine erosion. This was due partly to rapid subsidence and partly to rapid accumulation which protected the surface.

The exposures from which this reconstruction has been built are too numerous to list here, since the unconformity is very well exposed and quite easy of access (Plate IId). Because it occurs at the foot of cliffs often over 500 ft. (153 m.) high, there is considerable danger from falling rock, and for this reason not all of the outcrops noted were examined in detail.

IX. STRUCTURE AND TECTONICS

1. TRINITY PENINSULA SERIES

Structural observations in the Trinity Peninsula Series were made at Bald Head. The general lithology of these beds and the fact that no marker horizons were found has already received comment. Despite this difficulty, dip and strike measurements at each outcrop of the Trinity Peninsula Series throughout this area showed that the sediments had been folded isoclinally and that two anticlines and their complementary syncline occur at Bald Head. Due to the absence of suitable mapping horizons, it could not be determined whether or not the fold axes plunged. The strike direction of the rocks varies between 220° and 260° mag. This variation may have been caused by differential compaction or by two separate periods of folding, a major one from either the north-west or south-east, and another from either the north-east or south-west.

However these beds were folded, it is clear that the movements had been completed before Jurassic times and that a considerable amount of uplift accompanied them. Boulders of these contorted sediments are present in the Jurassic conglomerates at Camp Hill, and also in a volcanic agglomerate at Crystal Hill. A (?) Carboniferous age, based on some poor fossil plant remains found at Hope Bay (Adie, 1957, p. 1), has been assigned to the Trinity Peninsula Series. If this age determination is correct, the movements which were responsible for the contortion of these rocks must have taken place during Permo-Triassic times.

The Trinity Peninsula Series represents the first traceable stage of a migrating geosynclinal trough which was periodically uplifted throughout Jurassic and Cretaceous times. The Tertiary volcanic rocks of James Ross Island are also related to it. It will be apparent from later discussion that the rocks of north-east Graham Land are intimately related to the geosynclinal concept.

2. Middle Jurassic Series

a. *Mount Flora*

At Hope Bay the Middle Jurassic beds of Mount Flora rest unconformably on the Trinity Peninsula Series. The actual plane of contact is scree-covered but the inference of unconformity is based on sound evidence. Dips measured in the Trinity Peninsula Series vary between 22° and 48° to the west-north-west (285° true), whereas dips of the Jurassic sediments vary between 10° and 35° to the south-west (222° true). This is an angular unconformity with an azimuthal difference of approximately 063° between the direction of dips in the two series.

Three faults have been detected in the north face of Mount Flora. The easternmost, which is exposed on the north-east spur of the mountain, is vertical, trends north–south and has a downthrow to the east of approximately 90 ft. (27·5 m.). The second fault also trends north–south and hades very slightly to the east, which is its downthrow side. This normal fault throws tuff-quartzites against the plant-bearing shales with a displacement of 20 ft. (6·1 m.). The third fault was interpreted by Croft (1947) as a tear fault, a conclusion which has been neither confirmed nor denied. Croft gave the trend as almost east–west with a lateral displacement of 50 ft. (15·2 m.); the fault would be expected to re-appear in the west face of the mountain but it has not been observed there.

Faulting has been postulated to account for the absence of the plant-bearing beds on the south-eastern spur. If this is so, a fault must strike through the Mount Flora cirque. No faulting has been observed in the east face of the mountain. At the angle between the east face and the south-east spur several faults cut the Upper Jurassic Volcanic Group (Plate Vd). Assuming the dip of the Jurassic sediments to be constant, a downthrow of 400 ft. (122 m.) to the south-east is necessary to eliminate the sediments from the south-east spur.

No folding was observed within the Jurassic sediments other than of a minor nature. The apparent syncline noted by Andersson (1906) in the east face of Mount Flora is caused by the configuration of the surface rather than by actual folding.

b. *Botany Bay*

The structure in the vicinity of Botany Bay is clearly shown in Fig. 4. There is a well-defined asymmetric syncline whose western limb dips at 40° to the east, and whose axial trend is north-east to south-west. Away from the axial part of the syncline, towards the west, the dips become steeper as Church Point is approached. This can be interpreted in two ways: *either* as a structural anomaly caused entirely by the emplacement of the intrusive rocks of Church Point *or* as folding accentuated by the presence of a fault along which the Church Point intrusion has been emplaced. On the basis of the latter interpretation and the general topographic form of the area, Standring (1956, p. 28) has suggested the presence of a fault line passing through here and to the north of Crystal Hill and Bald Head. Further evidence relating to this is discussed in relation to the Upper Jurassic Volcanic Group.

In the vicinity of Camp Hill the syncline is cut by two faults, the westernmost of which trends north-north-west with a downthrow to the west of 40 ft. (12·2 m.). The eastern one trends north-north-east to south-south-west and has a downthrow to the east of between 400 and 500 ft. (122 and 152 m.). The younger rocks almost mask the structure on the eastern tip of the peninsula. A clue to the nature of the western limb of the syncline is provided by a small outcrop on the south coast, where it appears that the syncline continues beneath these beds.

Some workers have been of the opinion that the south-eastern coast of the peninsula was formed by a fault striking east-north-east to west-south-west. The only evidence of this is the trend of the straight-cliffed coastline which is parallel to other suspected faults and to Prince Gustav Channel.

It is probable that the Jurassic rocks of this area owe their surface outcrop to block-faulting and they comprise one of a series of blocks which are separated by the ramifications of the Prince Gustav Channel fault.

3. UPPER JURASSIC VOLCANIC GROUP

Rocks belonging to the Upper Jurassic Volcanic Group occur at Mount Flora and in three close but unconnected areas in Prince Gustav Channel: Bald Head, Crystal Hill, and Church Point and Camp Hill.

a. *Mount Flora*

The rocks of the Upper Jurassic Volcanic Group that occur in Mount Flora are cut by several faults. They are affected by all the faults described on p. 30. The faults of the south-east spur (Plate Vd) are particularly obvious and they sometimes provide a line of weakness for the emplacement of dykes. There is little evidence to indicate the time of faulting, but they cut both the Middle Jurassic sediments and the Upper Jurassic volcanic rocks. It is probable that they are contemporaneous with the deposition of the volcanic rocks.

b. *Bald Head*

On Bald Head itself an unconformity was discovered between the Trinity Peninsula Series and the Upper Jurassic volcanic rocks, the plane being exposed at station D.2774. This unconformity was traced accurately over the whole of the headland and the volcanic rocks were found to rest in a half-saucer-shaped depression in the metamorphic rocks. The contact appeared to be a normal terrestrial one, with boulders of the metamorphic rocks giving way to smaller size grades when traced upwards. The uppermost zones of the regolith were absent. A mixed rock at the base of the succession gave way to a tuff. The exact dip of the volcanic rocks was difficult to determine in the field but it must be about 10° to the south or south-east.

A low ice- and snow-covered col separates Bald Head from the mainland. On the north side of this col and along the shoreline to the east and west of it volcanic rocks similar to those forming the headland are exposed and, although the unconformity is not exposed here, the Trinity Peninsula Series was found close to the volcanic rocks at station D.2770. This proves the existence of the unconformity, and again it was possible to trace it with reasonable accuracy until it disappears beneath the sea. Projection of the planes of unconformity within these two areas reveals a difference in height of 770 ft. (235 m.) with a downthrow to the north. There are two possible explanations for this discrepancy: *either* a fault *or* an unconformity. The latter should not be regarded too lightly despite the discrepancy being so great within such a short distance, since there are numerous examples of the irregularity of the unconformity between the Cretaceous beds and the James Ross Island Volcanic Group on James Ross Island which are greater in magnitude than this. It has also been suggested that the unconformity is terrestrial, which is another reason for expecting irregularity. However, the balance of evidence points to the existence of a fault and the consequences of this assumption are discussed on p. 32.

c. *Crystal Hill*

The Crystal Hill rhyolitic rocks can be subdivided into two distinct groups: those occurring in the north and south of Crystal Hill, respectively. The rocks of the northern area are distinctive agglomerates containing a considerable number of angular fragments of already metamorphosed Trinity Peninsula Series sediments. The matrix is similar to that of the agglomerate group near Camp Hill, although the fragments in that rock are derived from the Jurassic conglomerates (fragments of Trinity Peninsula Series which are considerably more rounded than those of Crystal Hill). These rocks show little or no bedding, although the long axes of all the fragments in them are horizontal.

A disturbed zone separates these rocks from a well-bedded series of tuffs and rhyolites, which are in turn succeeded by more massive flow rhyolites with subsidiary tuffs. This zone is not visible on the east, because it is covered by a snow slope, but it appears in the cliffs on the west side of the headland. This is important evidence in relation to the question of a fault in this area, since it is directly in line with the Bald Head col and also with Church Point. It was not possible to determine the actual fault zone and therefore the disturbed zone is only quoted as evidence in support and not proof of the fault. The dip of the rocks south of the fault is approximately 10° towards the south.

d. *Church Point—Camp Hill*

The agglomerates are the basal rocks of the Upper Jurassic Volcanic Group in this area. The nature of the junction between the volcanic rocks and the underlying Middle Jurassic Series is in some doubt, and therefore it is necessary to determine accurately the relationship between that part of the Middle Jurassic Series which crops out beneath the agglomerate group and the more complete sequence in the west before this problem can be solved. This correlation is rendered difficult by the presence of a fault and the lack of faunal evidence. It therefore has to be done entirely on the uncertain basis of the flora. Because this flora shows no significant difference from the Botany Bay beds of the complete sequence, they have been correlated. This gives the fault a downthrow to the east of 400–500 ft. (122–152 m.). A close inspection of the contact gave only slight additional information, which tended to support the deduction that it is an unconformity.

No signs of either true or false bedding were observed in the agglomerates. They are overlain by rhyolites, whose occurrence *in situ* is confined to a very small, roughly circular area (D.2718) and in which no bedding is visible. A short distance away andesitic lavas and tuffs, presumably overlying the rhyolites stratigraphically, were observed dipping eastwards down a steep slope eroded in the agglomerates. As is to be expected in a volcanic group, all boundaries between major rock types are unconformities and erosion has occurred during the time intervals.

e. *Bald Head—Church Point fault*

There are three main lines of evidence which indicate the presence of a fault trending from Church Point to Bald Head:

i. The steepening of the dip in the rocks of the Middle Jurassic Series as Church Point is approached.
ii. The disturbed zone on the west side of Crystal Hill and the abrupt change in lithology there.
iii. The discrepancy between the heights of the planes of unconformity on the north and south sides of the col at Bald Head.

These are additional to the physical features; the fault has provided a line of weakness which has been exploited by ice erosion.

At Bald Head the downthrow of the fault can be calculated as approximately 770 ft. (235 m.) to the north. At Crystal Hill and Church Point, however, the apparent throw is towards the south but it cannot be calculated. In the rocks of the Upper Jurassic Volcanic Group there is considerable local variation, e.g. the andesites rest on the Trinity Peninsula Series at Bald Head, they are completely absent at Crystal Hill, and they occur with an unconformable relationship to rocks of the rhyolite group in the Church Point area. An accurate measurement of the throw can be obtained only where planes that can be stratigraphically related occur on both sides of the fault.

From regional considerations it seems likely that this fault has moved more than once, and in different directions, since it was first formed. Croft (1947, Pt. 8, p. 27) observed that "the rocks on the downthrow side of the fault [on Tabarin Peninsula] now stand at a higher level than on the other", and Standring (1956, p. 30) suggested that this difference could be explained by movements in different directions. The author has reached the same conclusion independently and considers that the northerly downthrow at

Bald Head is strong evidence for this line of reasoning. The envisaged movement is similar to that of the Highland boundary fault at Balmaha, Loch Lomond, Scotland.

The Bald Head fault is considered to be part of a wide network of faults that occupy Prince Gustav Channel. Faulting may also separate Bald Head from Crystal Hill and Crystal Hill from Church Point, since over 1,000 ft. (305 m.) of rhyolitic rocks are exposed at Crystal Hill but there are only a few feet at Church Point and none at Bald Head, whilst 200 ft. (61 m.) of andesites occur in the latter two areas. This may give some indication of the age of the faulting, the erosion of the rhyolites at Church Point having been almost completed before the andesites were erupted, whereas those at Crystal Hill must have been protected. An Upper Jurassic age is tentatively suggested for the initiation of faulting in this area.

4. Cretaceous System

In north-west James Ross Island where rock exposures are good it is possible to interpret the structure with considerable certainty. As the sedimentary succession is traced eastwards from Lagrelius Point there is a marked reduction in the angle of dip. The beds forming the cliffs south of Lagrelius Point are vertical or only a few degrees from it, but at Rink Point the dip is 56°, at Bibby Point 42°, varying from 20° to 30° between Brandy Bay and Stoneley Point, and only 5–10° at the head of Brandy Bay. In each of these localities the strike is in a direction 180–210° mag. and the direction of dip is eastwards.

At least eight separate exposures have been visited in the Hidden Lake area (D.3044–51, 3055, 3070, 3071), at one of which a continuous succession of 357 ft. (109 m.) was measured (Table III). All the dips recorded were 10–16° to the east with a strike of 200° mag. Towards the western coast of James Ross Island a steepening in the angle of dip was again observed and those recorded near Kotick Point were about 20–30° with a strike direction similar to that of the sediments inland. Although the structure here is not as marked as in the north of James Ross Island, it is still present. Fig. 6 shows the structure and distribution of the rocks in this area.

The structure of the west coast of James Ross Island is simple, forming one limb of a very asymmetric syncline whose axis is located in the vicinity of The Naze at the east end of Herbert Sound. It is curious that the western limb should become asymmetric within a distance of only 4 miles (6·4 km.) from Prince Gustav Channel, when the folding over the remainder of the island is so gentle. This indicates either the presence of a monoclinal flexure of great magnitude or the interruption of the sequence by faulting. That the Cretaceous beds could not have extended very much farther westwards is indicated by their constituents, since they had their origin on or near the mainland of Graham Land, less than 20 miles (32 km.) from the first outcrops of the Cretaceous.

A situation which parallels this is found near the Highland boundary fault south of Stonehaven, Kincardineshire, Scotland, where an asymmetric syncline striking north-east to south-west has an extremely steeply dipping northern limb and a less steeply dipping southern one (Macgregor and Macgregor, 1948). A comparison of the succession and rock types in the Lower Old Red Sandstone in which this syncline is developed shows further parallels with the Cretaceous sequence to the east of the Prince Gustav Channel fault. Both successions are principally of very coarse conglomerates, derived from older metamorphosed series, with intercalated sandstone bands, though the succession in Scotland is thicker and contains a volcanic element which is not present in Graham Land. The conglomerates swept outwards by torrential streams from the mountains and laid down as boulder deposits would presumably have had a shallow initial dip on deposition. This has been accentuated by drag folding along the fault as it developed and the thickness of conglomerates increased. The beds of western James Ross Island are envisaged as wedge-shaped deposits, thinning out rapidly in an easterly direction and being replaced by a finer-grained thinner sequence.

The structure in the Cretaceous, once it is represented at the surface by the Snow Hill Island Series, becomes increasingly difficult to decipher. The lithology of these rocks has been described (p. 22) and it will be appreciated that dips are poorly preserved. Where they were measurable, they were conformable neither in amount nor strike. It seems that the beds east of Brandy Bay, which are mainly exposed on the southern shore of Herbert Sound and at Cape Lamb, Vega Island, dip very gently eastward, but at The Naze they are horizontal. Dips recorded by Croft at Humps Island were confirmed (5° in a direction 260° mag.). There are no further exposures until those on Ula Point but here there are no measurable dips. On Rabot Point definite easterly dips of 10° were recorded and those on the south side of Hobbs

Glacier confirmed this. No good measurements were obtained from Hamilton Point but the easterly dip is still maintained at Snow Hill and Seymour Islands.

From the above descriptions it is clear that all dips are eastwards with the exception of the horizontal strata of The Naze area and the westerly dip at Humps Island. Therefore, great structural importance centres on the dips at Humps Island, because they are the only direct evidence of folding in the Cretaceous beds of James Ross Island east of Prince Gustav Channel. If these dips are disregarded and an average dip of 5° is assumed over the greater part of James Ross Island, a thickness of approximately 45,000 ft. (13,715 m.) is obtained for the succession and this is difficult to believe.

If the Humps Island dips are considered the following picture emerges. A broad shallow asymmetric syncline extends from Prince Gustav Channel eastwards with its axis in the vicinity of The Naze. The eastern limb of this syncline is represented by the Humps Island beds. There are no exposures in the area between Humps Island and the Ula Point—Rabot Point area but this must be the site of an anticlinal axis.

The Cretaceous of James Ross Island must therefore have been folded very slightly along axes trending north-north-east to south-south-west. A calculation of thickness based on this assumption gives 17,000 ft. (5,180 m.), a figure which agrees quite well with that given by Thomas (1949, fig. 3) for the thickness of the Upper Cretaceous in Magallanes Province, Chile.

Faulting in the Cretaceous follows two main patterns: a north—south trend connected with Prince Gustav Channel and an east—west trend. The north—south set of faults is discussed in connection with Prince Gustav Channel (p. 35). The east—west faults have been observed at five localities in the James Ross Island group:

i. On the north-west coast of James Ross Island 2 miles (3·2 km.) south of Brandy Bay, where there is a small fault with a downthrow of 30 ft. (9·1 m.) to the south-west; dykes and intrusions are associated in this area.
ii. Across the south of James Ross Island, as described by Stoneley (1953, p. 51).
iii. On Snow Hill Island where the downthrow is 20 ft. (6·1 m.) and the hade is 60°.
iv. On Cockburn Island, where a large fault brings Tertiary sediments into contact with Cretaceous sediments on the south (Croft, 1947, Pt. 5). Judging from the unconformity it may be expected to cut the coast of James Ross Island north of Rabot Point.
v. In the bay north of Tumbledown Cliffs. This fault was discovered as a result of the stratigraphical correlations between the outcrops of the Cretaceous sediments on the west coast of James Ross Island and their detailed mapping (Fig. 6). The downthrow of this fault is to the south and is about 900–1,000 ft. (275–305 m.). The Kotick Point Beds to the north are brought against the younger Stoneley Point Conglomerates but the actual contact has been eroded by a glacier. The presence of a fault here was demanded by the lithological change across the bay and by the lack of stratigraphical space which is determined by the occurrence of the Snow Hill Island Series near Cape Obelisk (Plate IId). This is the largest fault mapped, and like the smaller one near Brandy Bay it is associated with intrusions (D.3058, 3077).

5. JAMES ROSS ISLAND VOLCANIC GROUP

No faulting of post-James Ross Island Volcanic Group age, except that described in relation to Prince Gustav Channel, was observed by the writer. Stoneley (1953, p. 50) has reported the probability of a fault parallel to the southern coast of James Ross Island.

Due to the predominance and scale of current-bedding, folding affecting this group is difficult to detect. In the coastal section between Cape Lachman and Bibby Point, undulations in the bedding that were not obviously due to current-bedding were observed. They affect beds which are grouped with a marine facies of the James Ross Island Volcanic Group. No structures corresponding to this have been detected in the Cretaceous beds beneath, apart from a change of strike direction from the usual 200° to 180° mag., which may or may not be related.

Within this same area but more pronounced towards Bibby Point the marine facies rests with a distinct angular unconformity on rocks of the Cretaceous System (Plate Ic). Apart from this, no feature of structural value was observed.

X. DISCUSSION ON THE ORIGIN OF PRINCE GUSTAV CHANNEL

ONE of the striking topographic features of the north-east Graham Land area is Prince Gustav Channel. It was discovered in October 1903 by Nordenskjöld (1905), who sledged up it from his base station at Snow Hill Island. Since then its origin has been the subject of considerable speculation. The actual channel is merely part of a much bigger geological structure, since a plot of the distribution of rocks of the James Ross Island Volcanic Group shows that the line marking their easternmost extent makes a smooth curve from Active Sound and the Firth of Tay (between Dundee and Joinville Islands) across Tabarin Peninsula (north of Brown Bluff and Buttress Hill) and thence down the channel separating all the islands from the mainland (with the exception of Long and Alectoria Islands).

Apart from the arcuate form of this line, the other striking feature is the thickness of the volcanic rocks and the height of the rocks to the east of this line, and their absence on the mainland which is sometimes less than 1 mile (1·6 km.) away. The Swedish geologists, Andersson and Nordenskjöld, expressed the opinion that a fault was responsible for cleaving this area into two halves. Croft (1947) appeared to agree with this, but Adie (1953) pointed out that the arcuate distribution of the James Ross Island Volcanic Group could be due to the distribution of volcanic rocks from a centre, which he postulated as Mount Haddington. Stoneley (1953) suggested a reverse fault of low hade, while Standring (1956) disagreed and returned to the original idea of a fault, adopting certain modifications of Adie's hypothesis.

Most of these theories were based on the arcuate form of the boundary and the relative thickness of the rocks, and very little new information was introduced to support any of them since the time of Andersson and Nordenskjöld. During the present work information has been obtained which contributes to the solution of this problem when considered in relation to the general picture.

The structure of the Church Point and Bald Head areas has been discussed (p. 31) and the evidence for postulating a fault there has been stated. The trend of this fault is parallel to Prince Gustav Channel in this area. It is necessary to introduce a further fault between Bald Head and the Eagle—Egg—Tail Islands group to account for the absence of Tertiary volcanic rocks at Bald Head. If reversed movement has taken place in the one fault, it could easily occur in the other which is less than 1 mile (1·6 km.) from it. This would satisfactorily explain the difference in height between the islands and mainland, taking into account that the softer rocks of the islands erode more quickly than the metamorphic rocks of the mainland.

The structure of the Cretaceous rocks of James Ross Island has also been discussed (p. 33–34) and the opinion has been expressed that the sudden steepening of the dips as Prince Gustav Channel is approached is due to a form of drag folding associated with a fault of great magnitude, and probably aided by the initial dips of the sediments. Drag folding reaches its maximum at Lagrelius Point. Stoneley suggested there was a fault here, bringing the James Ross Island Volcanic Group agglomerates against Cretaceous sediments with a vertical contact, but he was also aware that it could possibly be an unconformable boundary. A detailed examination of the contact was carried out but there was no evidence of faulting in the gully which has formed at the contact. About 300 ft. (91 m.) from this gully, in another gully cut in the volcanic rocks, the bedding in the volcanic rocks changes markedly in attitude. It is well-marked in one block but with dips towards the east (the opposite direction would be expected if the beds were banked against a sediment cliff), and entirely absent from the next a few feet away. The question must remain open; faulting appears likely but the absence of fault breccias when folding of such magnitude is postulated is a serious drawback.

The opinion has already been expressed that the faults in the Bald Head area were active as early as the Upper Jurassic. Active uplift and vigorous erosion must have been taking place in Trinity Peninsula during the Upper Cretaceous in order to account for the nature of the beds on the west coast of James Ross Island. It is probable that the Prince Gustav Channel fault played a part in this movement. The downthrow to the east must have been extremely large (of the order of several thousand feet).

XI. GEOLOGICAL HISTORY

THE geological history of the north-east Graham Land area has been dominated by two major features. The first was the geosynclinal trough, which migrated across this area from west to east during a span of time extending from the early Carboniferous to the Miocene; the second was the fault zone along which Prince Gustav Channel has since developed. The latter modified but by no means obscured the effects of the former.

The original geosynclinal trough was established at an uncertain date but it was probably late Devonian or early Carboniferous. The sediments of the Hope Bay and Bald Head areas appear to represent an axial facies of this geosyncline. At some time prior to the Middle Jurassic, an orogenic episode with accompanying regional metamorphism affected these sediments. It was material derived from the erosion of a mountainous land formed by this orogeny that produced the Middle Jurassic sediments.

The Middle Jurassic strata are representative of the proximal facies of another geosynclinal trough then developing in the Weddell Sea east of the present position of James Ross Island. They were second-cycle sediments containing many conglomerates, sandstones, sandy mudstones and some shales. Their nature has been deduced from material found in the Cretaceous sediments, since their present extent is very limited. The Jurassic climate appears to have been warm and the land was heavily vegetated. At Hope Bay, a series of lacustrine sediments was deposited in a mountain basin, and a considerable amount of vegetable matter was included in the fine shales which overlie a series of coarse conglomerates and mudstones. A similar sedimentation cycle was operating in the vicinity of Botany Bay but, although the environment here was shallow-water and marine, conglomerates of varying degrees of coarseness, sandy mudstones, sandstones and shales were still being deposited. Some *ortho*quartzites indicate periods of relative stability and re-working of the finer materials to give a well-sorted deposit. Again, much vegetable matter was incorporated.

A rapid sedimentation cycle was brought to an end by considerable faulting (the Prince Gustav Channel fault system may have been initiated at this time) and widespread eruption of volcanic material. There are both andesites and rhyolites, the latter forming the bulk of the exposures. At Hope Bay rhyolites rest conformably on the Middle Jurassic sediments, but at Botany Bay there is an hiatus during which erosion occurred. The onset of volcanicity is certain to be diachronous and it is not a reliable time indicator. The accompanying earth movements caused the Middle Jurassic sediments to be folded about north-north-east to south-south-west axes, and this area remained unstable throughout the period of deposition of the volcanic rocks.

Sedimentation may have been resumed after the end of the volcanic phase. There are few indications of this but the considerable amount of re-worked glauconite in the Campanian beds of James Ross Island is anomalous. No glauconitic sediments have been found within the small areas of Jurassic rocks exposed at present. The age of the glauconite is not known, though near Hidden Lake it occurs sporadically throughout a succession from which derived Jurassic fossils have been obtained. It is therefore possible that it came from a Lower Cretaceous succession which is not represented at the surface at present.

Before or during Campanian times uplift of the mainland was renewed and the Jurassic sediments and volcanic rocks were eroded and "cannibalized" to form the Lower to Middle Campanian beds of James Ross Island. This is a well-known feature of geosynclinal cycles (Krynine, 1940) and it is particularly prominent in the proximal facies.

At the close of the Campanian there were movements along the Prince Gustav Channel fault, which resulted in the James Ross Island area being downthrown and the drag distortion of the Cretaceous beds. Probably at the same time a widespread regional uplift, associated with the emplacement of the Andean Intrusive Suite, was occurring. Considerable erosion was taking place at this time (Lower Tertiary) and the sediments of Cockburn and Seymour Islands were deposited with angular unconformity on the Cretaceous beds (Standring, 1956). Because they were formed from the Cretaceous rocks, this may represent yet another phase of "cannibalism" by a slowly developing geosyncline within the Weddell Sea area.

This phase was brought to a close by the introduction of new stresses which resulted in the development of a set of approximately east—west trending faults and the re-commencement of the subsidence of James Ross Island. This was shortly followed by the onset of volcanism in the Miocene which gave rise to the James Ross Island Volcanic Group and an increased rate of subsidence. Rocks of the Andean Intrusive Suite were exposed at the surface at this time. The western limit of this downward movement was the Prince Gustav Channel fault line and the mainland of Trinity Peninsula was not affected. When this volcanic episode ended a resumption of shallow-water sedimentation resulted in the formation of the Pliocene Pecten Conglomerate.

In post-Pliocene times a reversal of the throw of the Prince Gustav Channel fault occurred and the James Ross Island area began to rise. The rate of uplift since then has been faster than the rate of erosion and as a result the volcanic rocks now occur at a higher level than those of the mainland. Any volcanic rocks which might have extended to the mainland have been completely removed. General uplift of this whole area appears to be taking place at the present day, since phenomena associated with raised beaches have been found in the islands and, to a lesser extent, on Trinity Peninsula (Bibby, 1965).

XII. ACKNOWLEDGEMENTS

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PLATE I

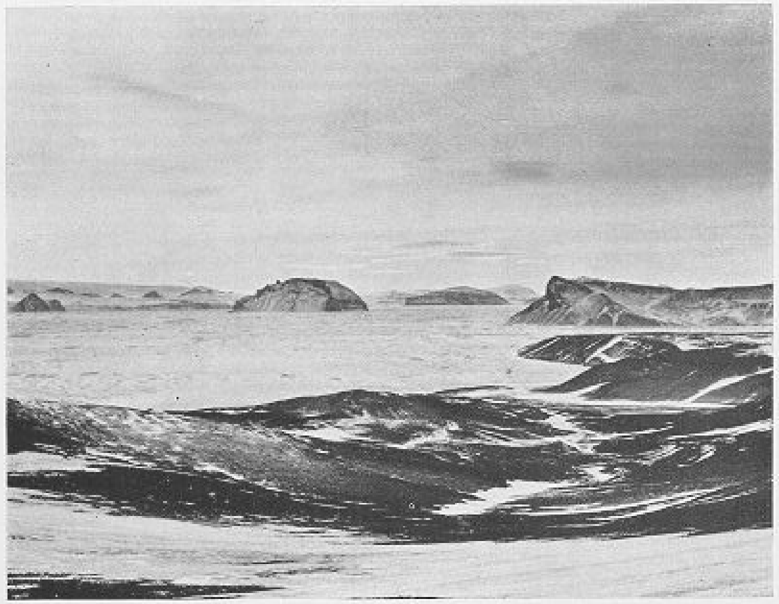
a. View northwards up Prince Gustav Channel from Stoneley Point, James Ross Island, with the Stoneley Point Beds in the foreground. Brandy Bay extends to the right, and to the north is a cliff of Cretaceous sediments buried by the James Ross Island Volcanic Group of Bibby Point. The prominent islands, Egg Island (right) and Red Island (left), are also composed of volcanic rocks. Church Point is on the extreme left, and the low peninsula between it and Red Island is Camp Hill which is composed of Jurassic sediments. In the distance are the greywackes of the Trinity Peninsula Series.

b. Prince Gustav Channel and a view of Trinity Peninsula showing the ice piedmont and the Detroit Plateau.

c. Bibby Point, James Ross Island, and the mainland of Trinity Peninsula in the vicinity of Victory Glacier. This illustrates the physiographic differences between the two areas. The ground in the left centre is occupied by Cretaceous sediments, whereas that to the right of centre is formed by the Bibby Point marine facies of the James Ross Island Volcanic Group. The unconformable contact can be clearly seen.

d. View across Hidden Lake, James Ross Island, towards the east, showing a mesa formed of the James Ross Island Volcanic Group surmounted by an ice cap which shows differential melting due to aspect (north is on the left). The moraines in the centre indicate the extent of the ice from the small cirque glacier during the equivalent of the Koettlitz glaciation.

PLATE I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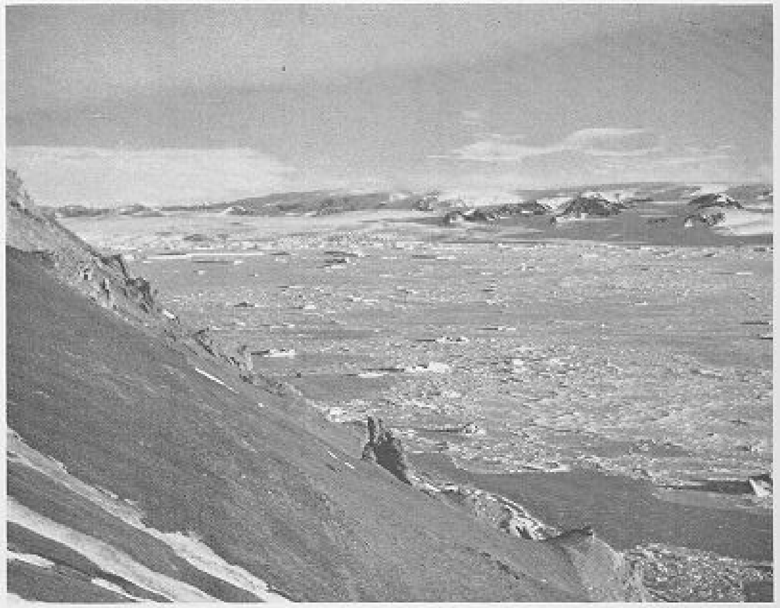
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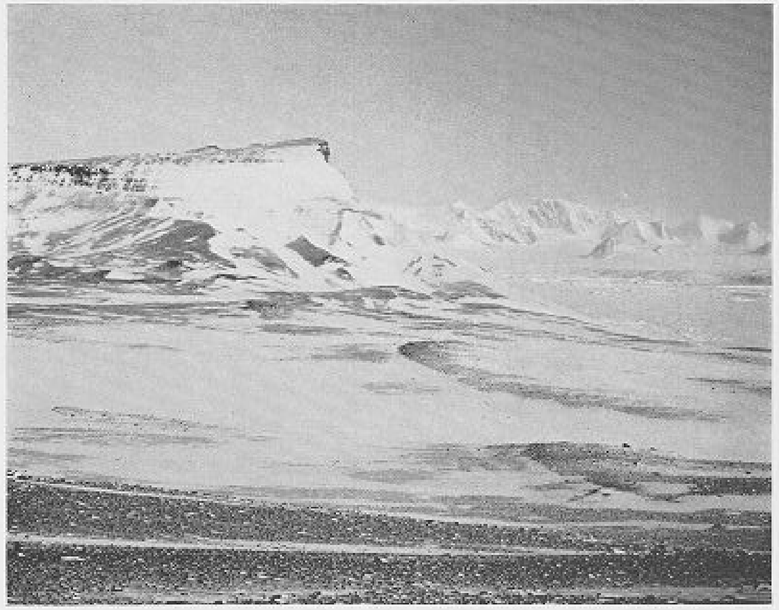
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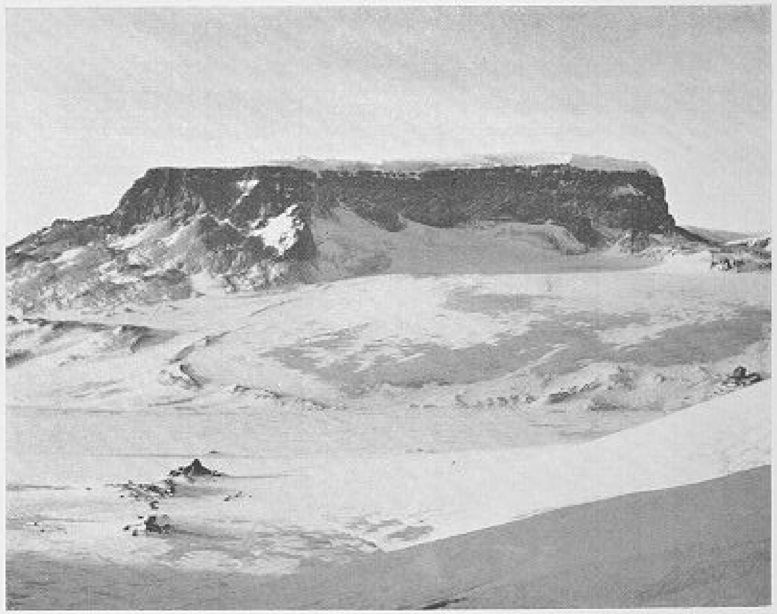
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PLATE II

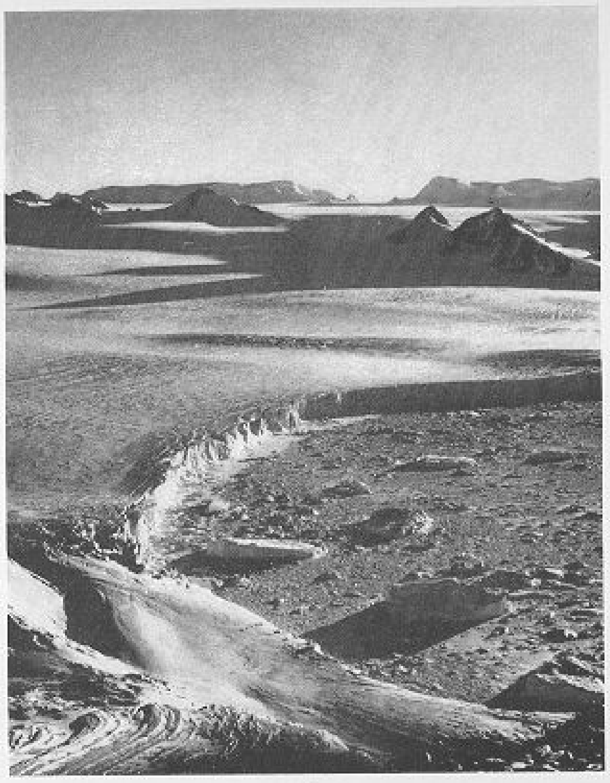
a. The northern aspect from the ridge 2·5 miles (4 km.) north of Bald Head, showing topography typical of the northern part of Trinity Peninsula. Wide glaciers take the place of the ice piedmont and the plateau is more broken. The pyramidal form of the peaks is maintained. Dead ice laden with rock debris can be seen in the lower left.

b. Inclusions of Cretaceous pebbles in a lava flow at the unconformity between the Cretaceous beds and the basalts of the James Ross Island Volcanic Group. West of Hidden Lake, James Ross Island; 1,000 ft. (305 m.) a.s.l. (D.3049).

c. Granitic boulder (lower left) included in a coarse marine agglomerate near Bibby Point, James Ross Island. The finer well-bedded material above the clinometer probably accumulated during a period of quiescence.

d. The obelisk, a well-known landmark on the west coast of James Ross Island. It is composed of basaltic tuffs and has resulted from frost-shattering along well-developed vertical joint planes. It rests on a plinth of friable sandstone and uncemented Cretaceous sands dipping away from the observer at 2–3°.

PLATE II



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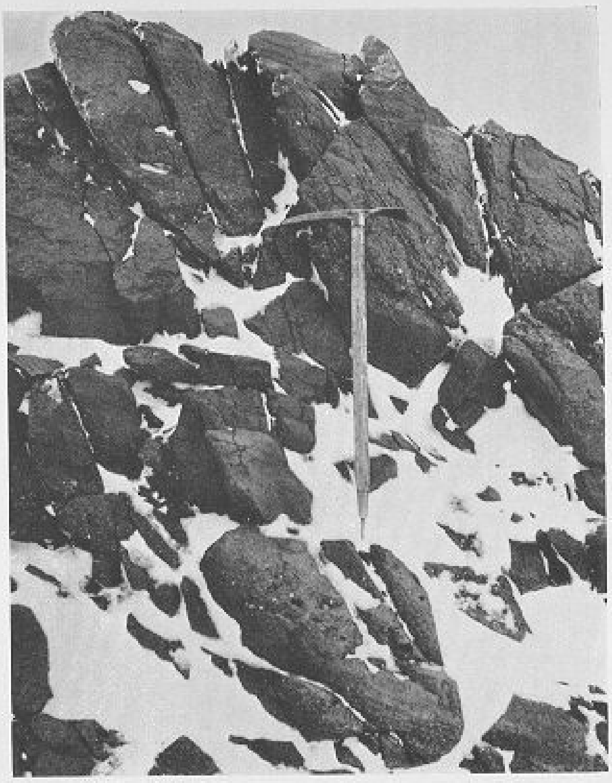

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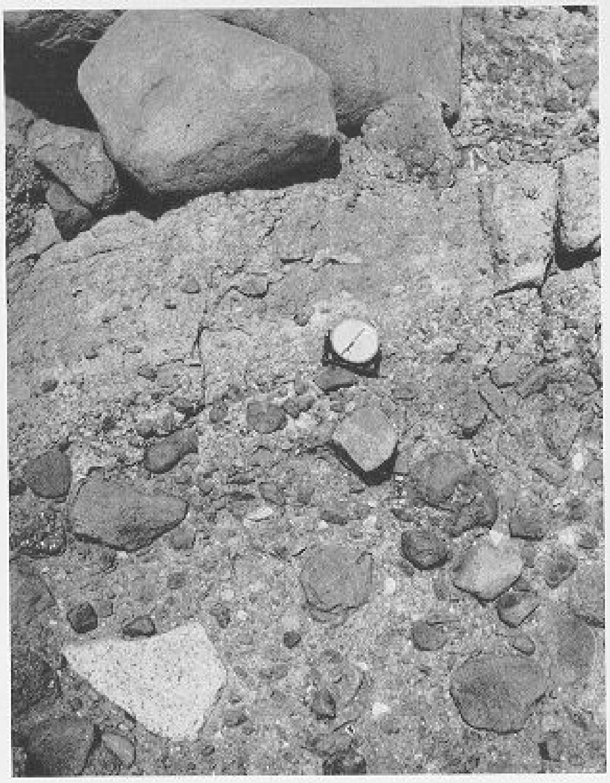

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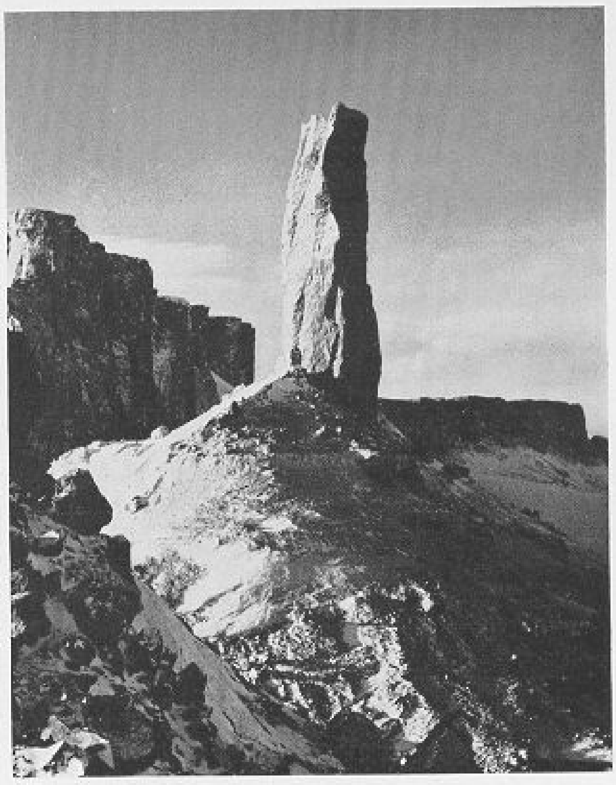

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PLATE III

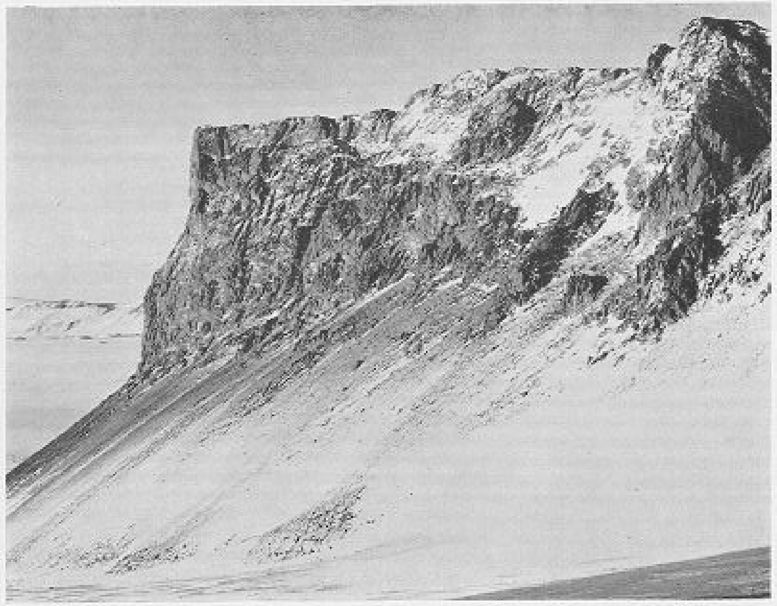
a. 750 ft. (230 m.) high cliffs of Upper Jurassic rhyolites and rhyolitic tuffs at Crystal Hill, Trinity Peninsula. Well-developed columnar jointing is present in the upper part of the cliff, and the axes of the columns are at an angle to the cliff top.

b. View of the west face of Mount Flora, Hope Bay. The plant-bearing beds are not present on this face. The transition between the sediments at the foot of the cliff and the volcanic rocks in the upper part occurs in the light band across the centre of the cliff.

c. Cretaceous sediments which crop out 1 mile (1·6 km.) south of Kotick Point on the west coast of James Ross Island.

d. A general view of the cliffs of upper Kotick Point, James Ross Island, where scree development is a common feature. The crag to the left of centre is formed of James Ross Island Volcanic Group rocks, which overlie the Upper Kotick Point Beds unconformably.

PLATE III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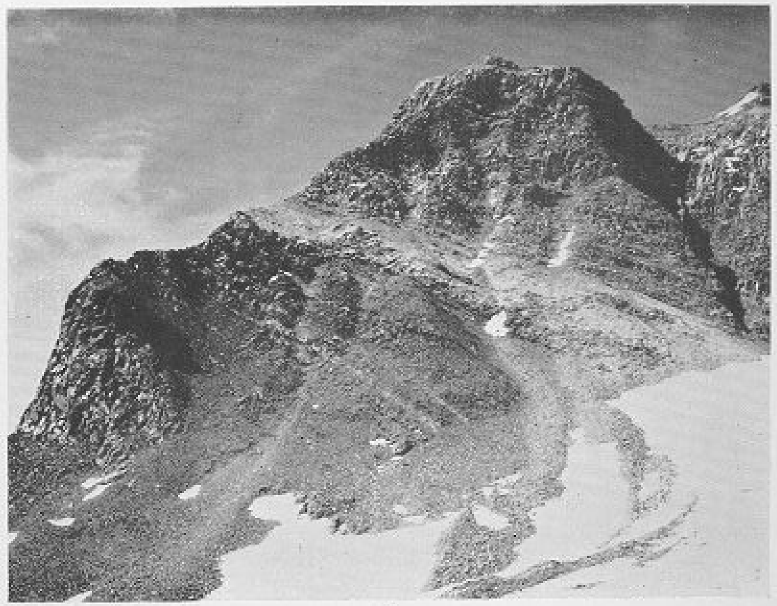
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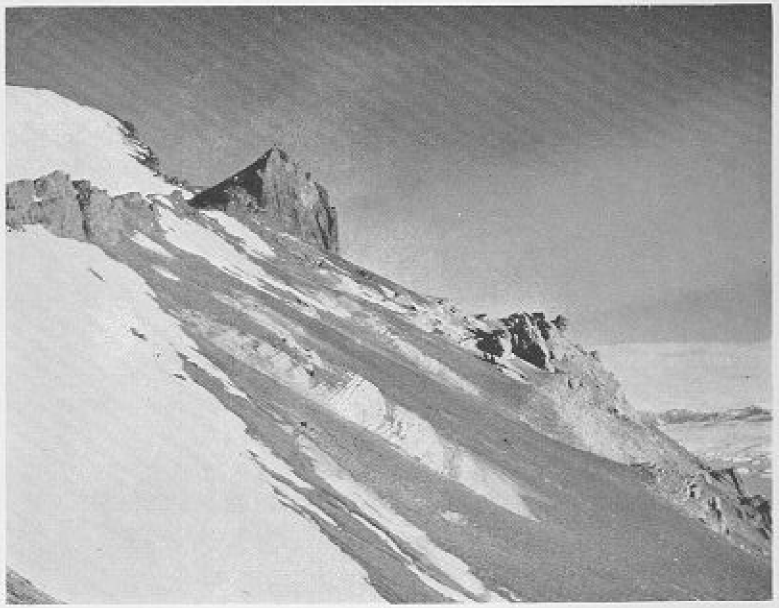
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PLATE IV

a. Friable Cretaceous sandstones of the Upper Kotick Point Beds at Kotick Point, west coast of James Ross Island.

b. Lenticular iron staining developed in the Cretaceous sediments at Kotick Point, James Ross Island. Some lenses are parallel to the bedding planes, whereas others are at a slight angle. They were not seen to penetrate the overlying conglomerates.

c. Boulders of conglomerate, probably of Jurassic age, within the Cretaceous Upper Kotick Point conglomerates at Kotick Point, James Ross Island.

d. Bedded sands and mudstones of the James Ross Island Volcanic Group west of Hidden Lake, James Ross Island. Ophiuroid impressions were found in the finely bedded sediments in the lower half of the photograph (D.3072).

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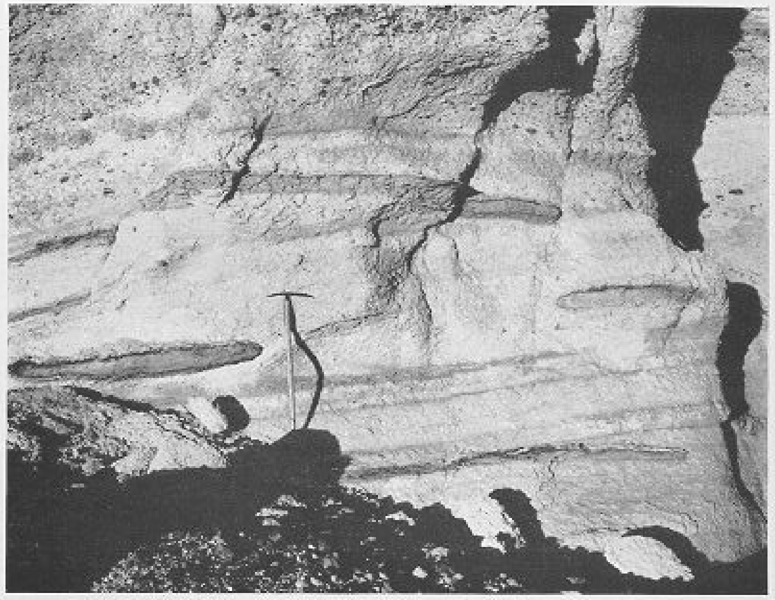

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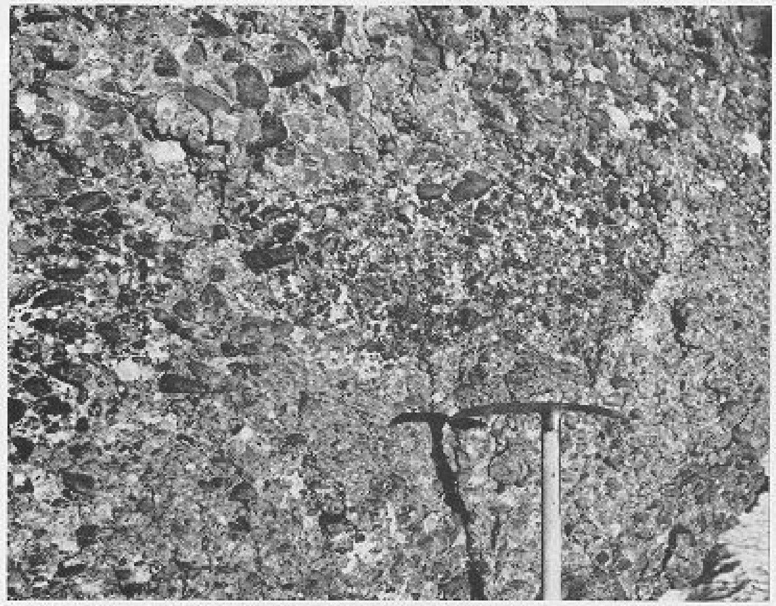

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PLATE IV

PLATE V

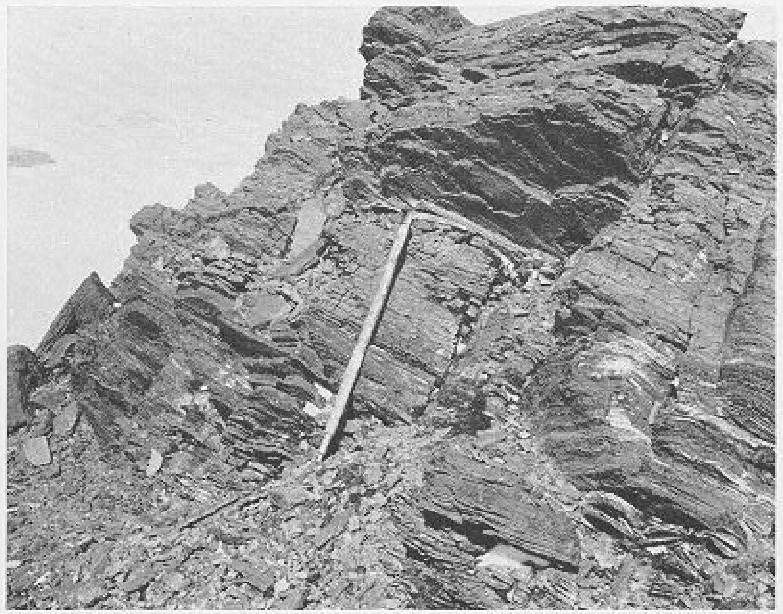
a. Sediments in which impressions of ophiuroids were found west of Hidden Lake, James Ross Island. They represent a basal marine facies of the James Ross Island Volcanic Group.

b. Pillow lavas showing selvages and concentric banding in the basaltic rocks of the James Ross Island Volcanic Group; 2 miles (3·2 km.) from Cape Lachman, James Ross Island.

c. A cliff of Cretaceous sediments buried by tuffs of the James Ross Island Volcanic Group 2 miles (3·2 km.) south of Lagrelius Point, James Ross Island. The volcanic rocks form the cliffs at the top and left of the photograph, and the sediments form the cliffs to the right. Tor development, a marked feature of the cold erosion cycle, is also illustrated.

d. The Upper Jurassic volcanic rocks of the east spur of Mount Flora, Hope Bay, viewed from The Pyramid. Dykes and small-scale faulting are present. Hope Bay is between Mount Flora and Mount Bransfield (in the clouds).

PLATE V



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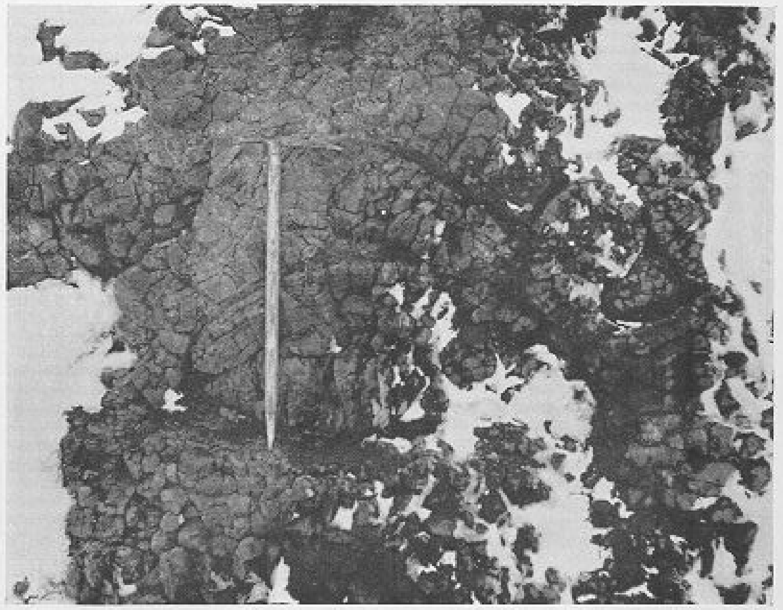

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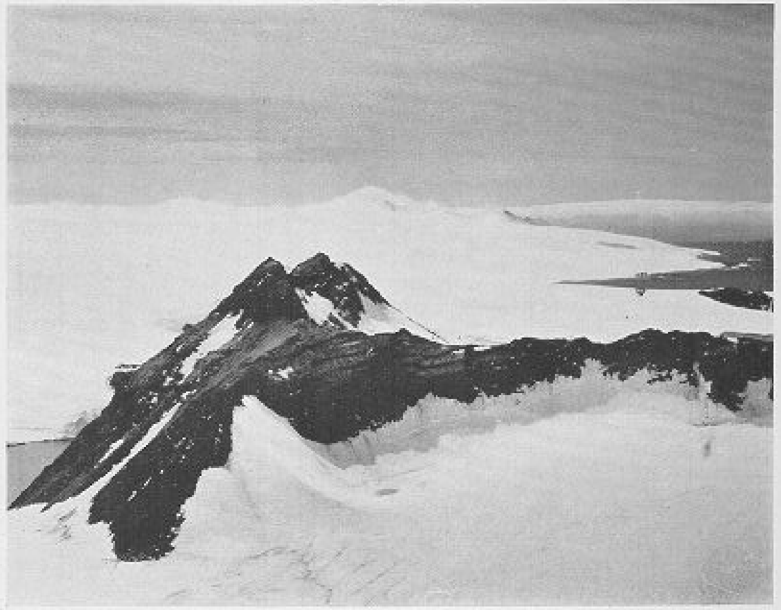

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