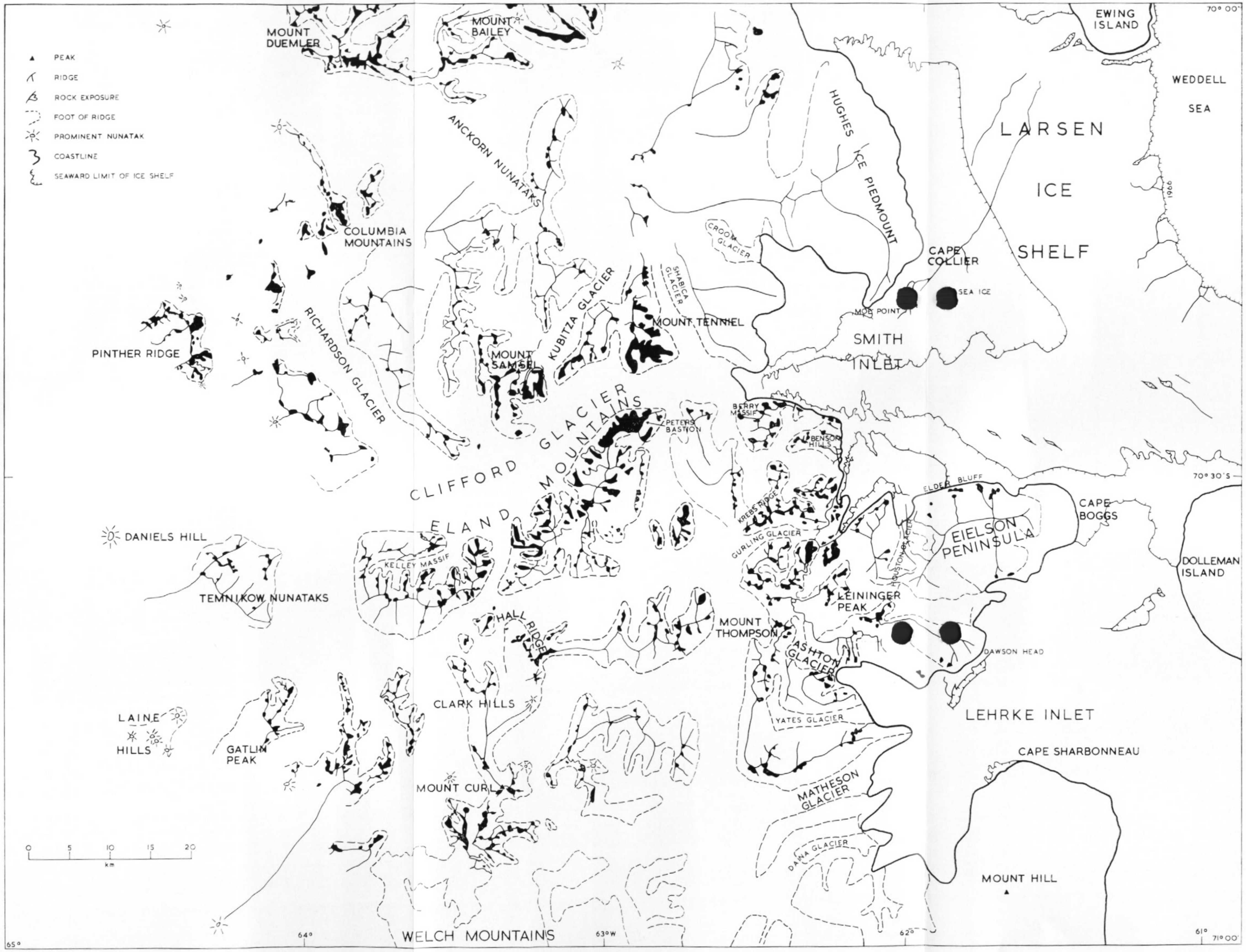

Fig. 1. Physiographical sketch map of part of north-eastern Palmer Land.

THE PHYSIOGRAPHY OF PART OF NORTH-EASTERN PALMER LAND

By J. F. ANCKORN

ABSTRACT. The physiography and glaciation of part of north-eastern Palmer Land are described and the controls affecting these factors are discussed. In particular, the striking differences between the respective topographies of Graham and Palmer Lands are noted and evidence for the recession of the Palmer Land ice cap is presented.

PALMER LAND, the southern half of the Antarctic Peninsula, lies between lat. 68°30′ and 75°00′S. The area discussed here is bounded by lat. 70° and 71°S. and long. 61° and 65°W. Exploration of the east coast of Palmer Land began in 1928 with the historical flight of Wilkins (1929) and in 1935 with that of Ellsworth (Joerg, 1936). However, it was not until the British Graham Land Expedition, 1934–37, that more detailed study began (Rymill, 1938); in December 1936 a survey party reached the Columbia Mountains. Parties from the United States Antarctic Service Expedition (1939–41) visited the Eland Mountains and Eielson Peninsula in 1940–41, carrying out survey and geological work (Black, 1945). In 1947–48, a joint British/American expedition surveyed the coast from the Larsen Ice Shelf as far south as lat. 75°S., and trimetrogon air photographs were taken (Mason, 1950). This photographic cover was extended by the U.S. Navy air survey in 1966–67, and the current U.S. Geological Survey sketch map of Palmer Land (Fig. 1) is based on this. Ground control was provided by the Directorate of Overseas Surveys in conjunction with the British Antarctic Survey, whose systematic exploration of the area began in 1966. The findings presented here are a continuation of this work, which was carried out during the austral summers of 1973–74 and 1974–75.

MAIN PHYSIOGRAPHIC FEATURES

The plateau

It is apparent that a distinct change in the character of the Antarctic Peninsula plateau occurs at about lat. 68°30′S., where the peninsula widens from 70 to 230 km. North of this latitude, the 1,500–2,000 m. high plateau is deeply dissected and has a continuous low-relief profile. No major peaks rise from this postulated Middle–late Tertiary surface (Nichols, 1960). Its margins are defined by 1,000 m. high cliffs and ice falls, broken by steep, fast-flowing outlet glaciers.

South of lat. 68°30′S., the plateau rises to heights of over 2,000 m. and major massifs such as the Eternity Range (Fig. 2), the Welch Mountains and Mount Jackson rise from this level to over 3,000 m. Linton (1964) suggested a modest pre-glacial relief for the Graham Land plateau "of the order of several hundreds of feet and locally as much as 1,500 feet [450 m.]". It is clear that a pre-glacial relief for the Palmer Land plateau must be considerably greater, of the order of twice that of the northern plateau, and subglacial topography (Smith, 1972) supports the conclusion that the Palmer Land plateau was certainly not a peneplain at the time of burial by the present ice cap (Fig. 3). Thus, while Graham Land supports a true dissected rock plateau, the Palmer Land plateau is actually an ice cap, under which is buried a rugged mountain chain. It is significant that "Neny Trough", a postulated fault line, separates these two upland areas. In this context, the comments of Znachko-Yavorskiy (1971) are relevant: "The pre-Neogene topography of the above-mentioned geostructures [the Antarctandes] seems to have been rather smooth. It was characterized by well-developed plains with an absolute height not exceeding 500–800 m. The mountainous topography was preserved only locally in those regions which had been subjected to the latest and most intense Mesozoic orogenesis (Palmer Land and Alexander Island)."

The Dyer Plateau forms the western margin of the area discussed here and at lat. 70°30′S.

Fig. 2. The Eternity Range viewed from the south-west with Mount Charity nearest to the camera.

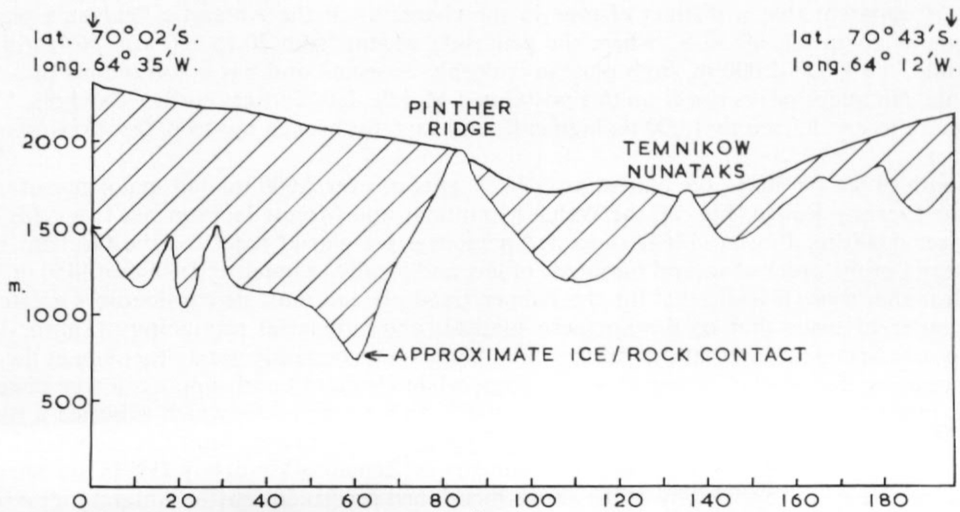

Fig. 3. Subglacial topography revealed by radio-echo sounding (Smith, 1972). The vertical exaggeration is ×40.

it comprises a 25 km. wide featureless snowfield. The height of the plateau crest descends gently from 2,260 m. at lat. 70°S. to just over 2,000 m. in the Mount Jackson area. The descent from plateau level to the Larsen Ice Shelf occurs over a horizontal distance of 25 km. in a series of contour-following terraces punctuated by numerous extensive rock ridges and nunataks. West of the 2,000 m. contour in this area, no rock is exposed along the plateau crest and the divide between Bertram Glacier on the west coast and Clifford Glacier on the east coast has the configuration of a 2,000 m. high col between the Eternity Range and the Welch Mountains.

Plateau-edge ridges and nunataks

The ridges which flank the plateau all possess a common feature in that they form a retaining wall for plateau accumulation, their western slopes are low and largely snow-covered, merging with snowfields at or rising to plateau level. In contrast, the southern and eastern faces are precipitous, display active cirque erosion and rise from ablated fields of old blue glacier ice.

Pinther Ridge, a north–south-trending crescentic ridge, displays all these features and rises to 2,277 m. on the dominant central peak, the junction of three rock faces undergoing cirque erosion. To the north-west, plateau-level snowfields flank both sides of the ridge and rock exposure is limited to protruding ribs with swagging (Linton, 1964) developed on the steeper southern slopes (Fig. 4).

North of Pinther Ridge, the plateau edge trends eastward to meet the western slopes of the Columbia Mountains as a 1,700 m. terrace, along which small nunataks emerge and are separated by ice falls and transverse crevasses. This feature forms the headwall of Richardson Glacier, a southward-flowing tributary of Clifford Glacier. The Columbia Mountains rise to 2,000 m. and support four ridges extending up to 4 km. in a south-easterly direction (Fig. 5). These are the remnants of more extensive divides and they are probably pre-glacial in origin. Although the massive pink intrusive rock has allowed the development of spectacular cliff faces and rock spires (Fig. 6), the general form is the plateau-edge type.

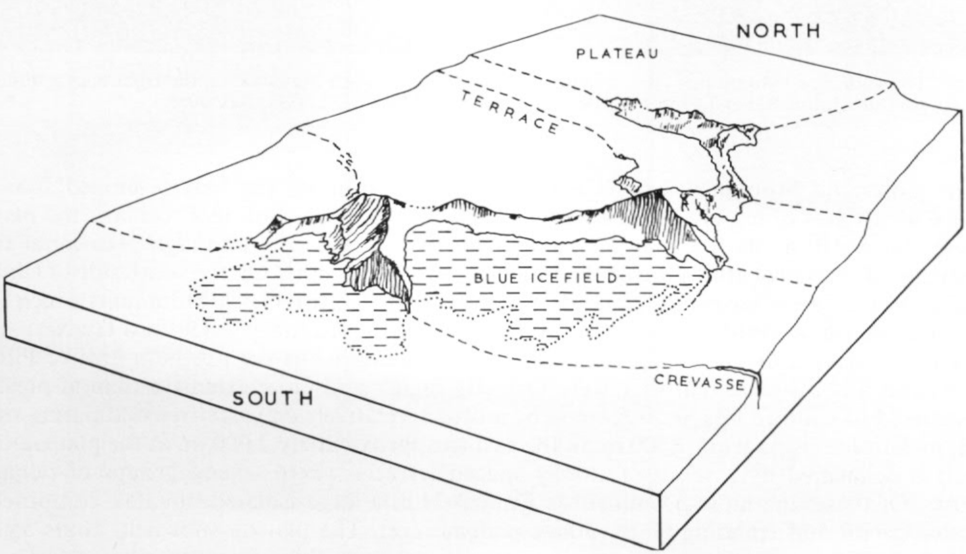

Fig. 4. Idealized block diagram of the configuration of the terraced snowfields and blue icefields surrounding Pinther Ridge. The ridge is viewed from the south-east. (Based on air photograph T.M.A. 1831. F31. No. 0049.)

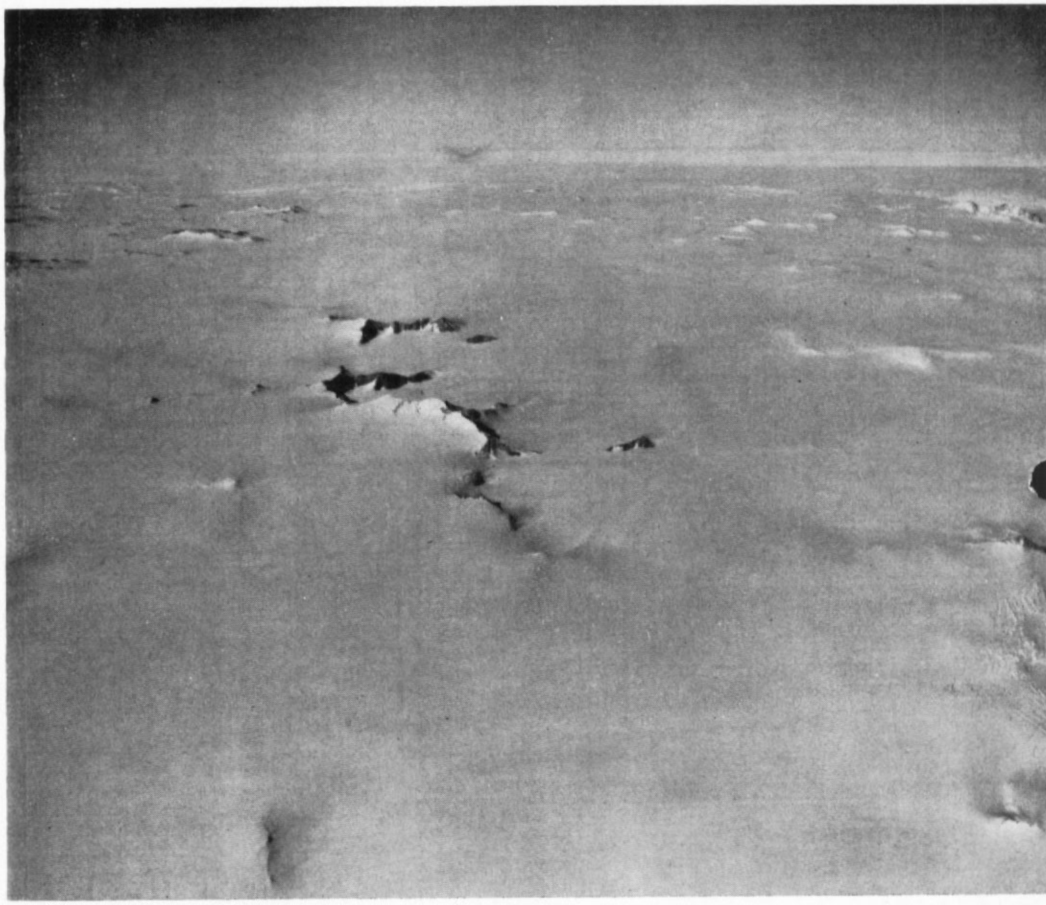

Fig. 5. The Columbia Mountains viewed from the west with Anckorn Nunataks in the right background and part of Mount Bailey to the left. (Air photograph T.M.A. 1831. F33. No. 0053.)

The Columbia Mountains extend 6 km. to the north along the well-developed 2,000 m. terrace as a series of closely associated nunataks. This terrace continues to mark the plateau edge as far north as the Eternity Range and no rock is exposed, although occasional small fissured ice domes probably indicate its presence at no great depth. On the south side of Clifford Glacier similar forms are exhibited by the northern ridges of the Welch Mountains which form the plateau-edge headwall of a sluggish northward-flowing tributary of Clifford Glacier. All of these ridges have a distinct lack of residual surfaces, except for the northern arm of Pinther Ridge, and it is assumed that they were formerly higher and more extensive than at present.

The head of Clifford Glacier is formed by a broad, relatively crevasse-free undulating snowfield, its altitude rising from 1,500 m. in the east to approximately 2,000 m. at the plateau edge, which is delineated by a series of closely spaced terraces where several groups of nunataks emerge. Of these, the most prominent is Daniels Hill, a large isolated nunatak composed of massive dacitic tuff standing 90 m. above plateau level. The plateau snowfield abuts against the nunatak on its western side, whereas the sheer 130 m. high heavily corniced rock face rises from the lower eastern snowfield. This configuration is repeated at various levels to the south at Laine Hills and Temnikow Nunataks.

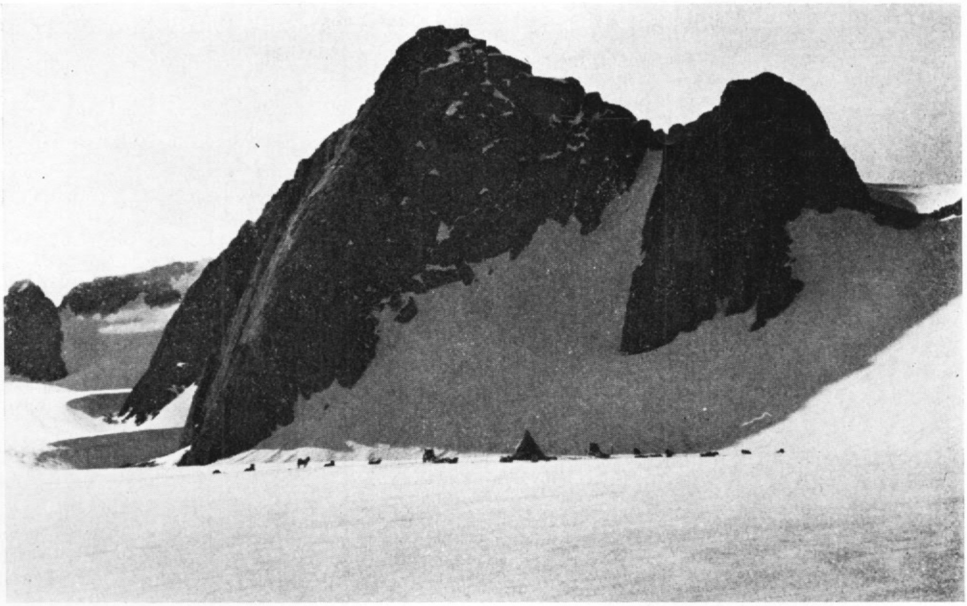

Fig. 6. One of the cliff faces, formed of massive granodiorite, in the Columbia Mountains (E.4421).

Nunataks north of Clifford Glacier

Eastward from the Columbia Mountains, schists and gneisses are exposed in a series of scattered nunataks which emerge from undulating snowfields. These descend from a height of 1,700 m. in the west in a succession of gentle slopes and terraces to approximately the 80 m. contour. Here, there is a major convex break of slope, which extends north to the foothills of Mount Bailey. Below this level, rock exposure disappears and the gradient decreases to the Hughes Ice Piedmont, terminating at Cape Collier.

These nunataks have the characteristic tendency to appear at distinct levels, closely following the ice terraces and emphasizing their control by the subglacial topography. The relief of these nunataks varies from 10 to 80 m. on their north-western sides and their southern faces fall abruptly by as much as 150 m. to the lower snowfield (thus repeating the form described above for plateau-edge nunataks). The dominant configuration is a low ridge with sporadic frost-shattered rock exposure along the crest but some conical nunataks also occur in Anckorn Nunataks, their rounded outlines enhanced by thick accumulations of *névé* on their leeward (south-eastern) sides.

Mount Tenniel, Mount Samsel and the Eland Mountains

These imposing massifs form the precipitous rock walls which contain the north-easterly flow of the deeply entrenched Clifford Glacier. The ice-sculptured forms of Mount Tenniel and Mount Samsel comprise the northern wall. The former has a distinct central peak reaching a height of 1,633 m. and from this four main ridges radiate to the north, south, east and west (Fig. 7). The northern flanks tend to be thickly blanketed by *névé* and overlapping ice, producing gentle slopes. However, the southern and eastern faces, vast truncated rock walls, plunge precipitously into the trench of Clifford Glacier. Beneath the southern face and extending below the heavily crevassed ice is a planed rock divide, its exposed northern extremity indicating continued recession of Clifford Glacier.

Mount Samsel, although composed of more fissile black schists than the massive gneisses of

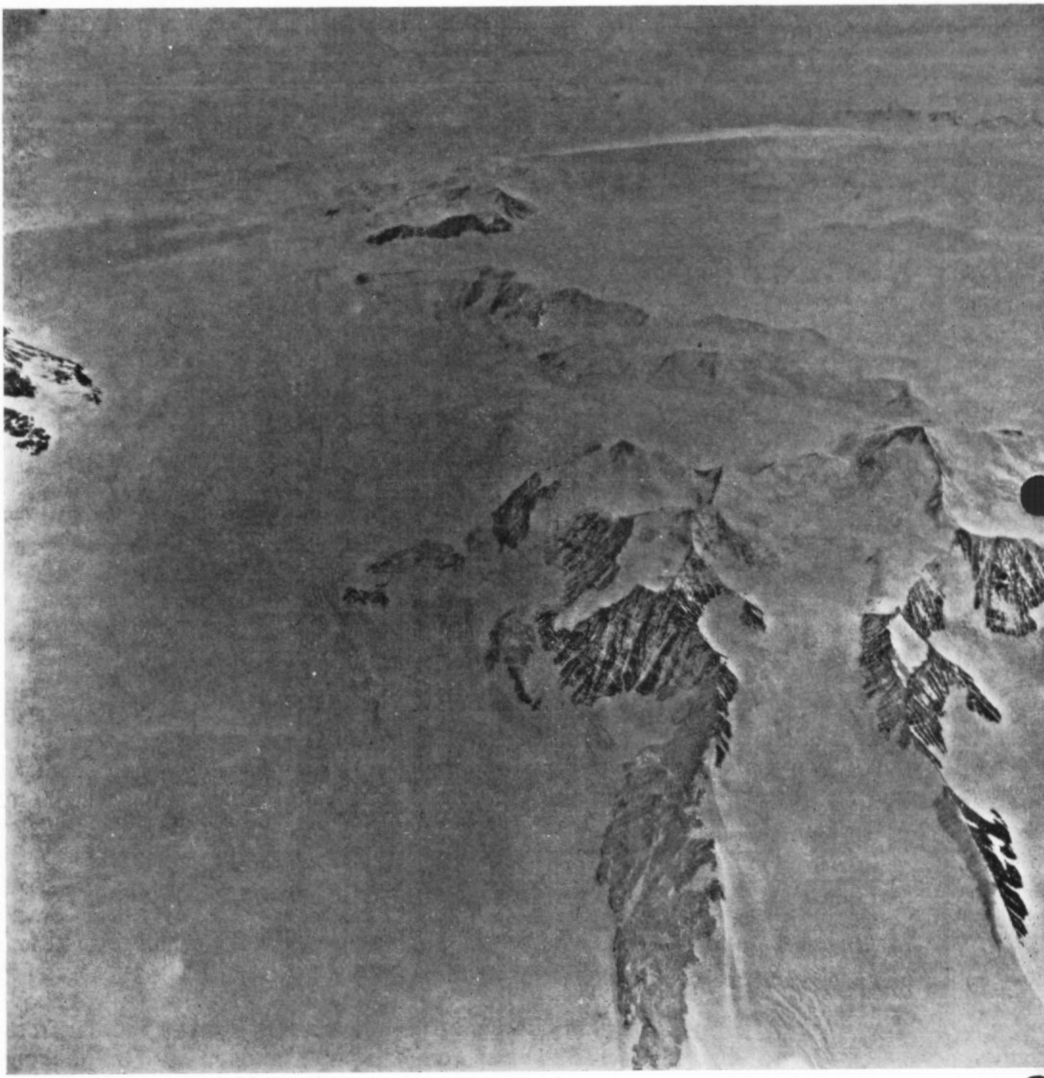

Fig. 7. Mount Tenniel viewed from the east with Clifford Glacier on the left. Note the planed rock step at foot of the southernmost face. (Air photograph T.M.A. 1816. F33. No. 0078.)

Mount Tenniel, has a similar form with four main arêtes radiating from a central peak. The southern ridges are truncated but, unlike Mount Tenniel, no extensive rock faces have been exposed. Thus Mount Samsel probably resembles Mount Tenniel at a stage when the Clifford Glacier trench was filled with ice.

The Eland Mountains (Fig. 8) form the south wall of the glacier and they extend 28 km. in a south-west to north-east direction as an unbroken barrier which reaches a height of 2,035 m. Their most distinctive feature is the 1,000 m. high north wall upon which sits the plateau-like summit, also noted by Davies (1976), who correlated it with similar forms in and around the Eternity Range. These residual features have been compared with the Graham Land plateau and both may be remnants of the Middle to late Tertiary pre-glacial surface. However, as has been suggested, the respective tectonic histories of Palmer Land and Graham Land in the

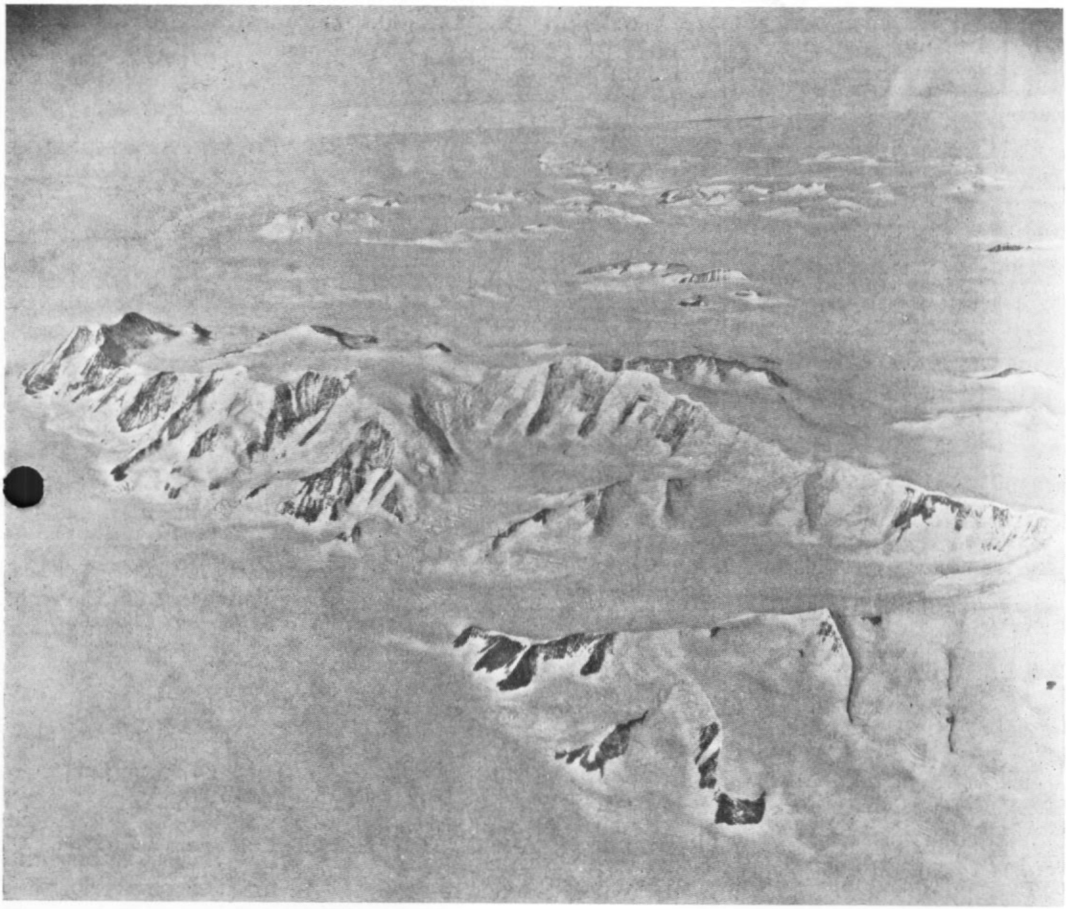

Fig. 8. The Eland Mountains viewed from the west across Clifford Glacier with their plateau-like summit. (Air photograph T.M.A. 1832. F31. No. 0045.)

Tertiary were probably quite different from each other and a direct correlation of physiographic forms may not be justifiable.

The arêtes on the north face of the Eland Mountains are truncated by Clifford Glacier and bear a distinct rock step about 200 m. above the present ice level. The south side of the mountains is a striking contrast to the rugged northern aspect. Here the slopes are mantled by a thick accumulation of ice which streams down from the plateau top as a steeply dipping snowfield whose contours are evidence of a rugged subglacial relief. At the north-eastern end of the mountains the summit plain is more deeply dissected and the reduced accumulation area has allowed the exposure of much rock and scree. The mountains are terminated to the south-west by a short north-easterly flowing tributary of Clifford Glacier beyond which is a modest system of interconnected scalloped ridges thickly mantled by ice and snow. Rising to the south of these ridges is an upland area crowned by Hall Ridge, composed of massive *ortho*gneisses, its peaks displaying swagging on their leeward (eastern) faces.

Eielson Peninsula

Separating Smith and Lehrke Inlets to the north and south, respectively, is Eielson Peninsula, which extends 55 km. from Mount Thompson eastward into the Larsen Ice Shelf. The massifs of Mount Thompson (1,691 m.) and Leininger Peak (1,136 m.) form a group of coastal mountains separated from Eielson Peninsula by a 300 m. high featureless col, which is possibly the manifestation of a block fault truncating Cape Collier to the north. The peninsula itself is a 700 m. high ice piedmont bounded to the north, east and south by precipitous ice falls which debouch on to the Larsen Ice Shelf. On the northern side, the ice cliffs are punctuated by a series of rock windows. The summit plain is a featureless snowfield which rises gently to a central height of approximately 700 m. In common with Hughes Ice Piedmont, these ice-mantled features show the increase in snow accumulation from plateau level to the Larsen Ice Shelf. Meteorological evidence underlines the fact that, while the coastal part of this area is one of steady accumulation, much of the hinterland and plateau-edge receives only sporadic accumulation or is being steadily ablated. The latter process is indicated by physiographic evidence.

Although this coastline is heavily covered by ice feeding the extensive Larsen Ice Shelf, two points are clear. First, the Wilkins and Black Coasts are areas of submergence, Eielson Peninsula being one of the many headlands that occur all the way along the Palmer Land east coast. Deeply entrenched outlet glaciers pour into the cliff-sided inlets; at a fairly constant distance of 15 km. offshore, Hearst, Ewing, Dolleman, Steele and Butler Islands form an archipelago originally regarded by Knowles (1945) as evidence of block faulting, which is continuous with the graben features of Cape Keeler. While there is no direct geological evidence to confirm this on the southern Wilkins Coast, physiographical aspects favour this hypothesis. Secondly, in spite of the headland and inlet form, it is overall an extremely regular and straight north–south coastline, a result of the dominant structural fabric.

GLACIERIZATION

Major glacial features

The gently undulating plateau ice cap of Palmer Land masks a rugged subglacial topography, the highest peaks emerging as the spinal massifs of the Eternity Range, the Welch Mountains and Mount Jackson. The role of this ice cap appears to be more protective than erosive but it also acts as a reservoir for the succession of outlet glaciers which pour east and west into the Weddell Sea and George VI Sound, respectively. In the area discussed here, Clifford Glacier fills this role, all other glaciers being either tributary to it or short coastal outlets such as Ashton and Matheson Glaciers. North of Smith Inlet, there are no well-defined outlet or valley glaciers until Anthony Glacier is reached; this stretch of coastline is mantled by a terraced piedmont glacier, Hughes Ice Piedmont. No outlet glaciers directly supply this area and it can be assumed that, like the Larsen Ice Shelf, a major proportion of its supply is collected *in situ*. The presence of ice-free stepped rock ridges in the Clifford Glacier trench and the recently emergent plateau-edge nunataks with planed summits indicate a general recession of the ice cap, a feature noted in most descriptions of the Palmer Land glacierization.

Clifford Glacier and its tributaries form a dendritic system, which, in common with other glacier systems of the Antarctic Peninsula, exploits a previously established drainage pattern, probably of Tertiary fluvial origin (Linton, 1964). This is indicated by the presence of long remnant inter-cirque divides on the north side of Clifford Glacier, and elsewhere it is clear that the present sluggish glacier system was not responsible for the striking drainage pattern developed around the head of this glacier. From geological and topographic evidence, it is likely that Mount Tenniel and the Eland Mountains were part of the same massif and that fluvial erosion followed by glacierization completed the breach.

In this area of stagnant or relatively slow-moving ice, crevassing is limited to Clifford Glacier itself, confluences with tributary glaciers and ice disturbances over shallow obstructions. Marginal crevasses are present along the whole length of Clifford Glacier but intense crevassing, such as to form serac fields, is limited to the snout where the glacier merges with the

Larsen Ice Shelf. Here, a 60 km. long snout of confused and broken glacier ice pushes out as far as the seaward edge of the ice shelf and its margins are marked by rifting. The effect of the eastward thrusting of the glacier snout is considered to be responsible for the opening of the ice shelf off Cape Collier to form an extensive rift now covered by sea ice and scattered icebergs.

Minor glacial features

In the coastal area (east of long. 63°15′W.) of moderately high accumulation, supraglacial moraines are absent. This is also the case farther inland, except in those areas where active ablation has produced blue icefields. Even on the relatively active Clifford Glacier, there is little supraglacial material in evidence and it is assumed that the debris spalled by active cirque erosion and frost action is quickly buried.

Blue icefields are present in two areas, both on the south-eastern sides of high mountain ridges, areas which receive funnelled plateau winds. Below Pinther Ridge, at stations E.4418 and E.4419, about 12 km.^{2} of exposed and superficially covered blue ice carries scattered angular supraglacial debris, individual boulders ranging in size up to 1·7 m. across. To the south-east of station E.4406, a 1·5 km. long line of moraine marks the boundary between two streams of ice flowing from either side of a rock ridge, the source of much of this material. The other blue icefield, on the south-eastern side of the Columbia Mountains below station E.4425, is less extensive but it is also covered by ill-sorted supraglacial material. Both icefields, although extensively fissured, are relatively crevasse-free and the polished surface is often wind-rippled and pock-marked with sunken rock fragments. It was observed that fresh snow is quickly stripped from this glazed surface by the 50 kt [25 m. sec.$^{-1}$] plateau winds and there is little doubt that the ablation responsible for the formation and preservation of such areas is caused by this agent, coupled with a meagre and intermittent precipitation.

Conclusions

The area immediately north and south of Clifford Glacier is mountainous, heavily glaciated and flanked to the west by a plateau ice cap, which masks a rugged spinal massif reaching over 3,000 m. in height. It is bounded to the east by the Larsen Ice Shelf and the Weddell Sea. Physiographic features, including exposed planned nunatak summits and rock steps, indicate a general recession of the ice cap, whilst a dendritic drainage pattern indicates that formerly erosion took place by fluvial processes.

However, the major land forms are thought to be controlled by a system of north–south-trending block faults, to which is partly attributed the dominant linearity of topographical features, including the position of the coastline and the off-lying low islands.

Acknowledgements

Thanks are due to Drs. R. J. Adie and P. D. Clarkson for their guidance in the preparation and presentation of this paper. In addition, I am grateful to all of my colleagues at the British Antarctic Survey stations at Stonington and Adelaide Islands during 1973–75, in particular E. G. Lawther and B. W. Care for their help and companionship in the field, and B. J. Conchie, pilot of the support aircraft, for operations often under difficult conditions.

MS. received 10 March 1977

REFERENCES

Black, R. B. 1945. Geographical operations from East Base. *Proc. Am. phil. Soc.*, **89**, No. 1, 4–12.
Davies, T. G. 1976. *The geology of part of northern Palmer Land, Antarctica.* Ph.D. thesis, University of Birmingham, 152 pp. [Unpublished.]
Joerg, W. L. G. 1936. The topographical results of Ellsworth's trans-Antarctic flight of 1935. *Geogrl Rev.*, **26**, No. 3, 454–62.

KNOWLES, P. H. 1945. Geology of southern Palmer Peninsula, Antarctica. *Proc. Am. phil. Soc.*, **89,** No. 1, 132–45.

LINTON, D. L. 1964. Landscape evolution. (*In* PRIESTLEY, R. E., ADIE, R. J. *and* G. DE Q. ROBIN, *ed. Antarctic research*. London, Butterworth and Co. (Publishers) Ltd., 85–99.)

MASON, D. P. 1950. The Falkland Islands Dependencies Survey: exploration of 1947–48. *Geogrl J.*, **115,** Nos. 4–6, 145–60.

NICHOLS, R. L. 1960. Geomorphology of Marguerite Bay area, Palmer Peninsula, Antarctica. *Bull. geol. Soc. Am.*, **71,** No. 10, 1421–50.

RYMILL, J. R. 1938. British Graham Land Expedition, 1934–37. *Geogrl J.*, **91,** No. 4, 297–312.

SMITH, B. M. E. 1972. Airborne radio echo sounding of glaciers in the Antarctic Peninsula. *British Antarctic Survey Scientific Reports*, No. 72, 11 pp.

WILKINS, H. 1929. The Wilkins–Hearst Antarctic Expedition, 1928–29. *Geogrl Rev.*, **19,** No. 3, 353–76.

ZNACHKO-YAVORSKIY, G. A. 1971. Main features of Antarctic neotectonics. (*In* ADIE, R. J., *ed. Antarctic geology and geophysics*. Oslo, Universitetsforlaget, 469–72.)