ORIGIN OF THE LANDFORMS IN THE FALKLAND ISLANDS AND SOUTH GEORGIA

DAVID SUGDEN

Senior Lecturer in Geography
University of Aberdeen

Prior to 1982 the title of this article would have sent many people scurrying to their atlases searching for the Falklands somewhere to the north of Scotland and South Georgia in the southern United States. Today there can be few people who don't have a clear impression of the scenery of the two island groups. They lie much closer to the equator than many people realise. The Falklands are situated in about 52°S and South Georgia around 54°S. In the Northern Hemisphere the equivalent latitudes would be central England and the Isle of Man (Fig 1). But they are separated longitudinally by 1600 km of sea, which is almost equivalent to the distance between the Shetland Islands and Greenland (Fig 2).

The landforms of the islands could hardly be more different. The Falklands consist of scenery reminiscent of eastern Scotland with rolling lowlands and gently sloping hill massifs. There are two main islands and the highest summits of each rise to only 700 m (Fig 3). The coast is indented with deep sinuous inlets and fringing islands (Fig 4). Most of the lower slopes are mantled in peat. South Georgia is quite different. Gentle slopes and lowlands are rare. Instead the island, which is 160 km long and 5-30 km wide, is little more than the crest of a mountain range (Fig 2). The centrepiece is the Allardyce Range with a profusion of ice and snow-clad peaks rising spectacularly to altitudes above 1700 m (Fig 5). The highest peak is Mt. Paget at 2960 m and the steepness of the scenery can be appreciated from the fact that this summit is only 7 km from the southern coast.

The contrasts between the two islands reflect their different geologic and geomorphic histories. In a nutshell the geological contrast is between part of a stable continent and a part of a mountain range while the contrasting geomorphic histories reflect the position of the islands on either side of the Antarctic Convergence, an oceanic boundary in effect separating the Antarctic domain from temperate environments.

Geologically, the Falkland Islands on the continental shelf of South America are part of the former super-continent of Gondwanaland (Adie, 1952). The main rocks and structures were formed when the island was attached to South Africa before the opening of the South Atlantic by plate tectonic movements. Indeed individual structures in the Falklands and the fossil content of individual geological beds may be closely matched with those in South Africa. The main consequence of this for the present day landscape is that the rocks and structures are over 180 million years old and that there has been a long period of time for the rock

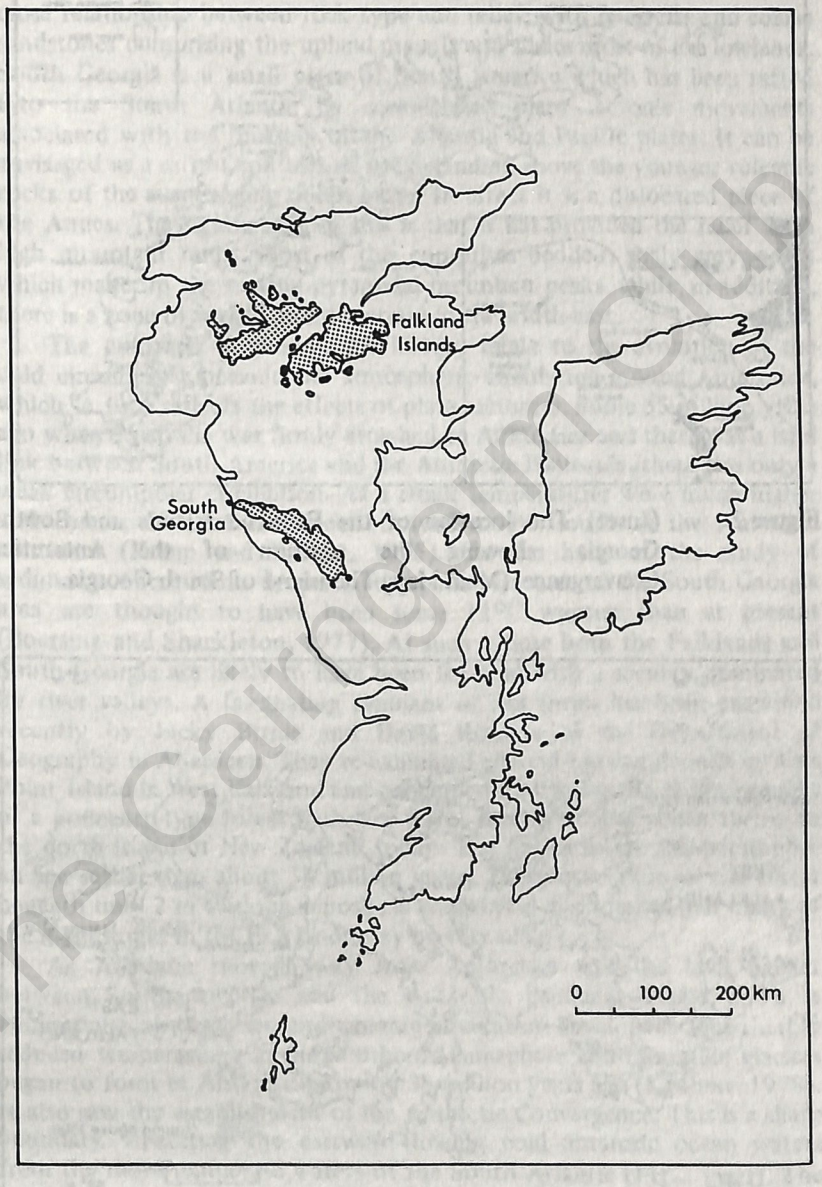

Figure 1 South Georgia and the Falkland Islands shown in their equivalent latitudes in the Northern Hemisphere.

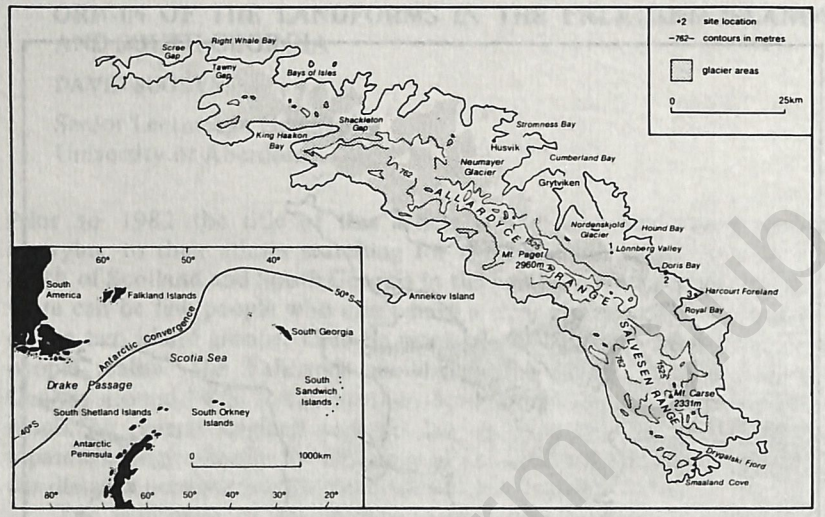

Figure 2 (Inset) The location of the Falkland Islands and South Georgia, showing the position of the Antarctic Convergence. (Main Map) The island of South Georgia.

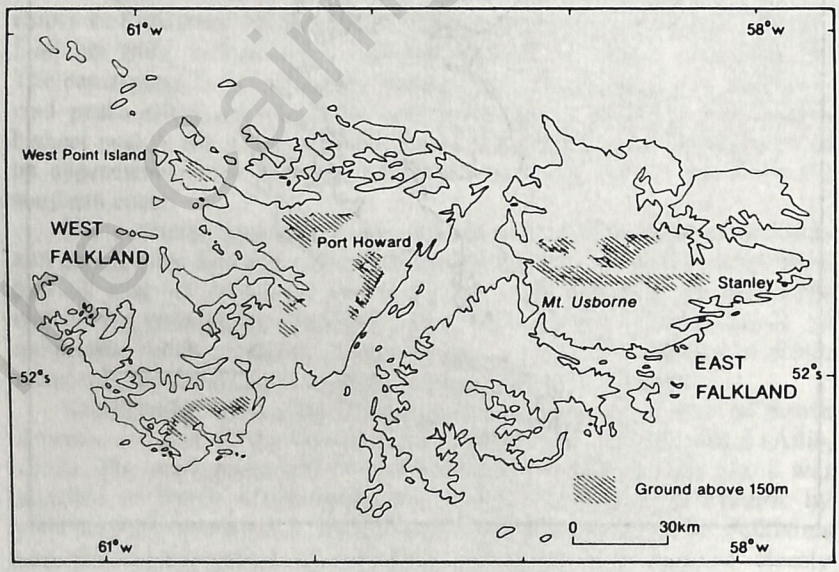

Figure 3 The Falkland Islands, showing the main upland and indented coast.

structures to be exploited by erosion. In practice this means that there is a close relationship between rock type and relief, with quartzite and coarse sandstones comprising the upland massifs and shales most of the lowlands. South Georgia is a small piece of South America which has been rafted into the South Atlantic by complicated plate tectonic movements associated with the meeting of the Atlantic and Pacific plates. It can be envisaged as a raft of continental rock standing above the younger volcanic rocks of the surrounding ocean basin. In effect it is a dislocated piece of the Andes. The significance of this is that it has provided the relief for a high mountain range. Most of this comprises bedded, shaly greywackes which make up the soaring pyramidal mountain peaks, while, in addition, there is a zone of rugged granite terrain in the south-east.

The contrasts in geomorphic history relate to the evolution of the cold circumpolar oceanic and atmospheric circulation around Antarctica, which in turn reflects the effects of plate tectonics. Some 55 million years ago when Australia was firmly attached to Antarctica and there was a land link between South America and the Antarctic Peninsula, there was only a weak circumpolar circulation. As a result temperatures were much higher and forests of southern beech thrived as far south as the Antarctic continent (Kemp and Barrett, 1975). On the basis of the study of sediments obtained in deep-sea cores, temperatures in the South Georgia area are thought to have been some 11°C warmer than at present (Boersma and Shackleton, 1977). At such a time both the Falklands and South Georgia are likely to have been forested with a scenery dominated by river valleys. A fascinating remnant of this forest has been examined recently by Jacky Birnie and David Roberts of the Department of Geography in Aberdeen. They re-examined a wood-bearing deposit in West Point Island in West Falkland and concluded that it was the *in situ* remains of a podocarp-type forest with tree ferns, similar to that which thrives in the north island of New Zealand today. The pollen in the deposit implies an age earlier than about 38 million years. The preservation of the forest beneath only 2 m of slope deposits is remarkable and implies that many of the main slopes in the Falklands may be very old.

As Australia moved away from Antarctica and the land barrier between South America and the Antarctic Peninsula broke down, a circumpolar atmospheric and oceanic circulation developed. This sharply reduced temperatures in the Southern Hemisphere and mountain glaciers began to form in Antarctica around 38 million years ago (Kennett, 1978). It also saw the establishment of the Antarctic Convergence. This is a sharp boundary separating the eastward-flowing cold antarctic ocean waters from the more temperate waters of the South Atlantic (Fig 2 inset). The boundary may represent a 5°C difference in water temperature over a distance of a few 100 m. The importance for the two island groups is that the Antarctic Convergence developed between the two and that subsequently over tens of millions of years South Georgia has experienced

Figure 4 Port Howard, a farm settlement in West Falkland is situated at the head of a sheltered sea inlet, which is a drowned river valley.

Figure 5 The snout of Harker Glacier, South Georgia. The corries and peaks of the Allardyce Range are in the background. (Photograph by Gordon Thom).

a sub-polar climate while the Falklands have experienced a cool temperate climate.

The contrast is best displayed by glacier extent today. Although it is only 250 km further south, South Georgia is heavily inundated with glaciers, while the Falklands are free of ice. The southwest coast of South Georgia, lying athwart the track of depressions sweeping round the Antarctic, receives an exceedingly heavy snowfall and virtually all rock slopes down to sea level are plastered in ice. Rock buttresses are encrusted in rime ice and frequently ice breaks off and, together with snow, avalanches onto glaciers which flow to the coast where they calve into icebergs and brash ice. The glaciers flow rapidly and their surfaces are sharply crevassed as a result. The lee north eastern side of South Georgia is less bleak (Birnie 1978). Here glaciers flow down to sea inlets (Fig 5) but there are also pleasant ice free peninsulas (Fig 6). The Falklands do not support glaciers today. Snowfall is relatively light and it rarely persists in the mountains, even in winter. It comes as a surprise to many to discover that the annual precipitation in Stanley is less than in Aberdeen. At present it is simply too warm on the highest Falkland summits for the little snow that accumulates there to survive a summer melt season and form a glacier.

The glacial expansions that have characterized the Ice Age during the last few million years in the Northern Hemisphere have also affected the Falklands and South Georgia and have added further contrasts to the two island groups. During glacial expansions the glaciers on South Georgia covered all lowlying peninsulas and extended offshore to form an ice cap 300 x 130 km in size (Fig 7). The evidence of this ice cap is seen in the glacially-scoured landforms of the coastal peninsulas where irregular rock knobs and small lochans produce a landscape similar to that of western Scotland (Fig 6). This scoured scenery also extends offshore. In places striations on coastal peninsulas tell of the direction of flow of overriding ice. The expanded ice cover was also responsible for the excavation of fjords and other troughs (Fig 6), with many features characteristic of erosion by glaciers, such as truncated spurs and overdeepened rock basins. Also the troughs may be traced offshore as prominent trenches incised into the shelf surrounding the island. In places the ice cap axis was offset from the present island axis and as a result ice flowed across the island. One result was the excavation of glacial valleys across the island, similar in many ways to the Lairig Ghru in the Cairngorms. One such gap has been named Shackleton Gap after the memorable crossing of the island by Ernest Shackleton in 1916. The middle of the ice cap is likely to have been no higher than about 900 m and as a result the mountains of the Allardyce Range would have protruded as nunataks, though they themselves would have been sculptured by corrie glaciers. Today there is a sharp morphological contrast between the knobbly terrain of the areas submerged by the ice cap and the sharp ridges of the mountains which were too high to be submerged.

Figure 6 An early winter snow cover on the ice-free north eastern side of South Georgia highlights the site of the old Grytviken whaling station at the head of a fjord bounded by ice-scoured peninsulas.

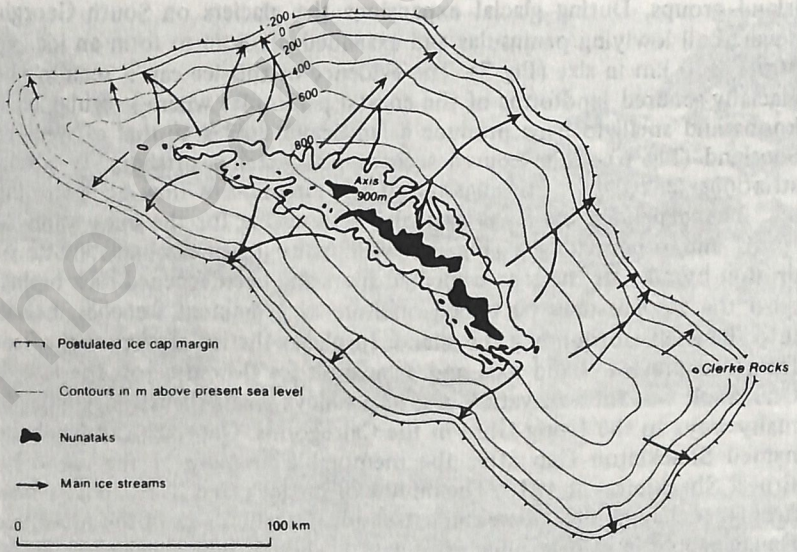

Figure 7 A reconstruction of the ice cap which extended offshore around South Georgia. The shaded areas mark the mountains which protruded above the ice surface as nunataks (From Sugden and Clapperton 1977).

Glaciation of the Falkland Islands was very limited. There are a handful of corries on the two upland massifs on East and West Falkland (Fig 8) and evidence of glacial deposits suggests the longest glacier was no more than 2.7 km long (Clapperton and Sugden, 1976). In addition there are a number of nivation hollows, excavated by snow patches. These are similar to corries but less well shaped. David Roberts has analysed these features and discovered that their predominant eastward orientation points to the influence of strong westerly winds. He is also able to demonstrate statistically that their locations are typical of an exceedingly marginal glaciation. Such conditions would occur with a mean annual temperature fall of 2°C. Exhaustive work has revealed no evidence of more extensive glaciation in the Falklands. This evidence of limited glacial activity throughout the many cold phases of the glacial epoch is interesting for such a cool temperate location. Probably the major explanation is the relative aridity of the islands which has kept total snowfall small.

The lack of extensive glaciation in the Falklands is perhaps the critical factor in understanding the contrast with the landforms of South Georgia. In the Falklands the lowland has not been scoured into an irregular rock and lochan topography, the pre-existing river valleys have not been deepened into glacial troughs and the surrounding offshore shelf is smooth and unmodified by ice action. Instead, gentle slopes leading down to rivers, which are well adjusted to rock structure, are the norm. The lower parts of these river valleys have been excavated to a level some 46 m below sea level (Maling 1960) and at some stage since they have been flooded to form rias, inlets of a type which is common in south-west England. Port Howard is a good example (Fig 4). The landings at Port San Carlos by the British Task Force in 1982 took place in one such drowned river valley and one reason for selecting this inlet was to seek protection from the valley sides.

It would be wrong to imply that glacial periods had little impact on the Falklands' landscape. Indeed, many detailed slope forms are related to downslope soil movement under periglacial conditions. The word periglacial is used to describe those cold landscapes which are not covered by glacier ice. The main characteristic is the presence of frozen ground where surface layers thaw only in the spring and summer. Under these conditions a saturated layer of surface soil or surface stones may move downslope under the influence of gravity. The overall process of soil flow is called solifluction and indeed the word was introduced by Andersson in 1907 following a visit to the Falklands! Today, if such downslope movement is frost assisted, it is commonly called gelifluction.

Gelifluction forms are widespread in the Falklands. The most famous are the stone stripes or stone streams. Typically these consist of 30-200 cm boulders of sandstone and quartzite and originate at rock outcrops on ridge crests. The boulders are arranged into stripes running down the valley sides, although in places they may form a sheet (Fig 9). The alignment of

Figure 8 Corries on the flank of Mount Usborne, East Falkland. (Photograph by David Roberts)

Figure 9 Stone stripes and sheets on a hillslope in East Falkland.

the long axes of the stones in a downslope direction and the sorting into stripes is typical of gelifluction and it seems reasonable to assume that stones, derived from the rock outcrops, have been moved down the valley sides. In certain places the boulders accumulate in the valley floors and one such accumulation, called Princes Street, is 6 km long and c. 800 m wide (Fig. 10). Other typical gelifluction forms are lobes bounded on their downslope sides by boulders. Such lobate forms are common in the Cairngorms in Scotland, for example in Lurcher's Gully. A final characteristic of intense periglacial action is the presence of rock outcrops on hill crests. Such resistant rock masses are left upstanding when active slope processes remove surrounding frost-shattered rock fragments. Good examples of such rock outcrops were seen in the television pictures of the hills around Port Stanley during the final days of the fighting in 1982.

The periglacial features of the Falklands are notable for their large size and fine degree of development. Probably there are two main reasons for this. First, the quartzite and sandstone rocks provide an unusually suitable source of boulders. Second, the islands were exposed to periglacial conditions throughout the cold periods of the last few million years. Both dating and morphological relationships suggest that the periglacial features were contemporaneous with the corrie glaciers. Unlike South Georgia (and indeed Scotland, Scandinavia and North America) where periglacial activity could take place only between glaciations, in the Falklands it could occur throughout the main cold periods.

Radiocarbon dates of peat on both South Georgia and the Falklands suggest that the last cold period was over by about 9,500 years ago (Clapperton *et al.* 1978). Since then both island groups have enjoyed climates similar to those of today, or at least that is the implication drawn from preliminary analysis of pollen contained in peat cores (Barrow, 1978). Nevertheless there are differences in the geomorphology of both islands resulting from this recent period of warmth. In South Georgia 9,500 years ago, glaciers had retreated from their last maximum position (c. 18,000 years ago) and were close to their present limits. Since then there has been a minor advance of the glaciers which has created fresh moraines several 100 m in front of existing ice fronts. A date in peat beneath one such moraine suggests the advance took place in the late 18th century (Clapperton *et al.* 1978). This date makes it the probable equivalent of the Little Ice Age advance which culminated in the 16th-19th centuries in most parts of the world.

Whereas peat growth is restricted in South Georgia, in the Falklands it forms a blanket over most of the islands varying from perhaps 30 cm to 2 m in depth. In many areas details of the underlying ground are completely obscured. The bottom of the peat has produced several dates of 9,500 years old and no older peat has yet been discovered. The implication is that any former cover of peat was stripped off during the last periglacial phase and that new peat was able to reform only after active soil movement ceased around 9,500 years ago.

Figure 10 The 'Stone Stream' of Princes Street, a vast accumulation of geliflucted boulders in a valley bottom.
(Photograph by David Roberts)

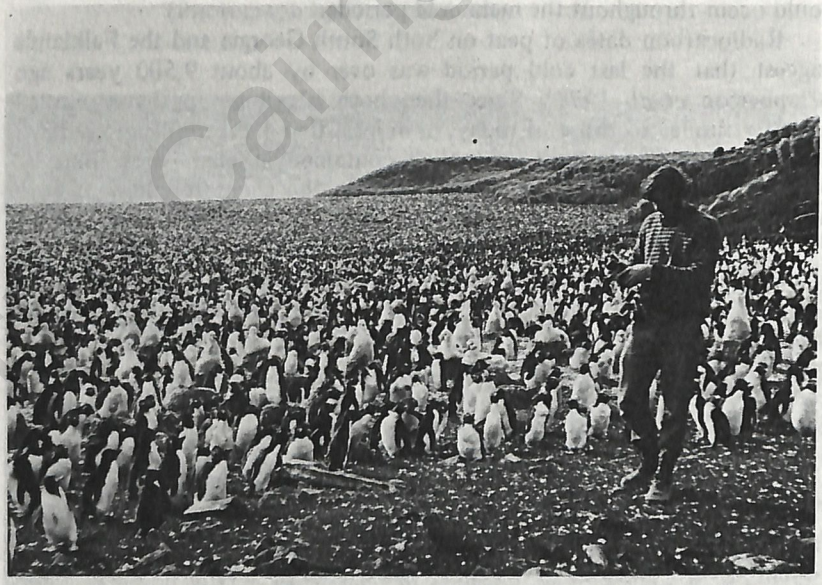

Figure 11 Penguins and albatrosses nesting on a popular raised beach, Beauchêne Island, Falkland Islands.
(Photograph by Gordon Thom)

Both island groups have evidence of recent variations in sea level. Curiously the reasons for the variations may be different in each case. In South Georgia there are raised beaches at 7.4 and 3 m above sea level. The upper beach, consisting of shingle ridges and raised terraces, is intimately associated with moraines marking former glacier positions and is related to the main phase of deglaciation perhaps around 10,000 years ago. It has been tempting to relate the elevation of this beach at least in part to the isostatic uplift of the island as it rebounded in response to the loss of the burden of overlying ice. However a raised shoreline also exists in the Falkland Islands at about 6 m above sea level. It is marked by terrace remnants of former deltas, raised shingle ridges, shell deposits and also by the way it truncates peat deposits in many areas (Fig. 11). David Roberts has obtained two dates on shells in the beach which suggest it is around 6-7,000 years old. In the absence of a former ice cap, isostatic uplift is an unlikely explanation for its elevation. Until recently it has been difficult to explain a rise in sea level of this amount at such a date. However, a new model of world sea level change which compensates for the effect of changing ice masses in modifying the earth's geoid, predicts just such a high sea level in the Falklands at such a time (David Roberts, personal communication 1983).

South Georgia and the Falklands provide fascinating contrasts in scenery. Starting with different geological bases, they have since experienced quite different climates, in spite of their similar latitudes. South of the Antarctic Convergence, South Georgia has been modified by glaciers during both glacial and 'interglacial' periods. Lying north of the Antarctic Convergence, the Falklands escaped massive glaciation and, instead, they represent a river landscape which has been repeatedly modified by intense periglacial activity.

Footnote – Dr. Sugden and his colleague, Dr. Clapperton, have each spent two seasons in the Falkland Islands and South Georgia and are planning another trip. Under their supervision, six research students have worked on the geomorphology of the islands and one of the students, Campbell Gemmell, was stranded in the Lyell Glacier hut on South Georgia during the Argentine occupation of Grytviken. He and his samples were evacuated by the Royal Navy, but his samples went to the bottom of the Falkland Sound when H.M.S Antelope was sunk. The many maps, booklets and photographs prepared by Dr. Sugden and his colleagues were used by the Ministry of Defence during the Falklands war and the assistance given by the Department of Geography was acknowledged by the Ministry of Defence. Dr. Sugden was guest speaker at the Club's Annual Dinner in 1976 and has addressed an Indoor Meet. He wrote an article in the Journal in 1977, CCJ Vol. 18, No. 97 pp 189/201, entitled 'Did Glaciers form in the Cairngorms in the 17th to 19th centuries?' – Editor.

REFERENCES

ADIE, R.J. 1952 The position of the Falkland Islands in a reconstruction of Gondwanaland. *Geological Magazine* 79(6) 401-10.

ANDERSSON, J.G. 1907 Contributions to the geology of the Falkland Islands, *Wissenschaftliche Ergebnisse der Schwedischen* Sudpolarexpedition, 1901-1903, Bd.3, Lief 2.

BARROW, C.J. 1978 Postglacial pollen diagrams from South Georgia and West Falkland Island. *J. Biogeography.* 5(2) 251-74.

BIRNIE, R.V. 1978 *Rock debris transport and deposition by valley glaciers in South Georgia.* Ph.D. thesis. University of Aberdeen.

BOERSMA, A. and SHACKLETON, N.J. 1977 Tertiary oxygen and carbon isotope stratigraphy, site 357. *Initial Reports of the Deep Sea Drilling Project.* 39, 911-924. Washington.

CLAPPERTON, C.M. & SUGDEN, D.E. 1976 The maximum extent of glaciers in part of West Falkland. *J. Glaciol* 17(75) 73-77.

CLAPPERTON, C.M., SUGDEN, D.E., BIRNIE, R.V., HANSOM, J.D. & THOM, G. 1978 Glacier fluctuations in South Georgia and comparison with other island groups in the Scotia Sea. In van-Zinderen Bakker, E.M., (Ed.) *Antarctic glacial history and world palaeoenvironments* Balkema, Rotterdam, 95-104.

KEMP, E.M. & BARRETT, P.J. 1975 Antarctic glaciation and early Tertiary vegetation. *Nature* 258, 507-8.

KENNETT, J.P. 1978 Cainozoic evolution of circumantarctic paleoceanography. In van-Zinderen Bakker, E.M. (Ed.) *Antarctic glacial history and world palaeoenvironments.* Balkema, Rotterdam, 41-56.

MALING, D.H. 1960 In Cawkell, M.B.R., Maling, D.H. and Cawkell, E.M. *The Falkland Islands* Macmillan 252 pp.

SUGDEN, D.E. & CLAPPERTON, C.M. 1977 The maximum ice extent on island groups in the Scotia Sea, Antarctica *Quaternary Research* 7, 268-82.