*Richard Clark**
Coleraine

PERIGLACIAL LANDFORMS AND LANDSCAPES IN THE FALKLAND ISLANDS

Abstract

The Falkland Islands experience a cool oceanic climate with a moderate rainfall. They are formed largely of sedimentary rocks which display a range of structures. Across the widest part of East Falkland, in a zone of folding of varied style, prominent quartzite beds form or strengthen high ground (600–700 m). This tract of hills and the surrounding lower ground is diversified by a series of erosion surfaces.

In its major elements this landscape shows the consequences of declining levels of planation but the products of cold climate geomorphic processes are widespread. In the past the long-known stoneruns have generally been regarded, whatever the details of formation postulated, as cold climate features. However, their place in a suite of landforms and their significance as a component in an erosion-transport-deposition system has not been previously established.

It is now possible to discuss this suite and the erosion system more completely, and to establish relationships between the various parts. Hilltops are characterised by blockfields, altiplanation surfaces and residual tors; hillsides by frost-riven crags, scree, block-terraces, and stoneruns. Valleys are largely encumbered by stoneruns and head, the latter also forming extensive sheets on the lower ground. Evidence of the consequences of severely cold climate is extended by the description of a number of corries (cirques) in the highest and most extensive uplands, of thaw lakes and depressions, and of patterned ground.

Amelioration of climate led to the formation of smaller debris terraces after the larger block-terraces ceased to develop. There is evidence that since the periods of most severe cold rivers continued to discharge much greater volumes and loads than they now do. That the phases of severe and declining cold were not a simple progressive sequence is shown in the interbedding of organic and mineral deposits noted from coastal exposures. Terrestrial deposits extend below present sea-level and drowned valleys are traceable to depths well within those possible during the last major glacio-eustatic withdrawal of sea. Coastal materials show that the climate was still subject to significant fluctuations at the time of recovery to present level. The present climate appears to be one of much reduced morphological activity with little frost action; rivers are generally sluggish and underfit.

Both worldwide and especially regional circumstances concerned in producing the local cold conditions are considered. The degree of cooling adequate to produce an environment rigorous enough to form the landorms was very similar to that for British and continental European periglacial phenomena.

INTRODUCTION

The importance of periglacial environments in the development of Falkland Islands landforms was well established by Andersson's (1906, 1907) studies of the vast stoneruns among the Falkland hills. Both before then and more recently (e.g. Joyce, 1950) the concentration of Falkland landform studies upon the stoneruns has resulted in the influence of a period of more severe climate being widely recognised, but the relationships of the stoneruns to

* Education Centre, New University of Ulster; Coleraine, Northern Ireland.

other features, and the parallel consequences of periglacial conditions elsewhere in the islands have received less attention. There is a series of periglacial landforms which in the uplands form an association which apparently has not been described previously as a contemporary interrelated suite of landforms. The archipelago of two major and very many smaller islands rises from the Patagonian Shelf between latitudes 51°00 and 52°30 S. and between 57°40 and 61°30 W. In total area it covers about 11,000 km^2, with East Falkland having an area of about 5,000 km^2. Such is the complexity and length of the coastline that no place lies more than 19 km from the sea.

In general the area is one of low ground with much land below 100 m. Hill, plateau, and mountainous country is rather more extensive in West Falkland than on the larger East Falkland where it is virtually confined to an east-west tract barely exceeding 30 km in greatest width and crossing the island at its widest extent (c. 100 km). The greatest height on East Falkland is 705 m at Mt. Usborne; three other hills exceed 600 m. The highest hills of West Falkland are in the same height range and lie in the same latitude as those of East Falkland.

Variously folded sediments of Lower Devonian to Lower Carboniferous age form the main uplands with sandstones, and particularly hard quartzose sandstones, producing the principal hill features. In East Falkland the close folding and east-west strike controls both the disposition of the main hill masses and the form of its component hills and valleys. Features are generally narrow and elongated in the direction of strike. In West Falkland there are more extensive plateau surfaces.

The restricted height and extent of uplands suggests that they can have only local climatic influence possibly restricted to attracting locally greater rainfall and producing adjacent rainshadows. The overall climate is the consequence of regional position, the fragmented land area, and a generally low relief. The rather inadequate precipitation data from the outlying stations and the data for Stanley suggest that uplands in the west and the central hill tract are the wettest areas with mean annual falls of about 700 mm.

The most characteristic feature of the climate is the coolness of summer, the four warmest months reaching only 8.1° to 9.3°C at sea level (monthly means). Three winter months with means of 2.2° to 2.5°C combine with the coolness of summer to produce a very small seasonal range strongly influenced by the coolness of the surrounding subantarctic surface waters which are rarely warmer than 9°C (range 6°–12°). The present climate is not of periglacial type though it would require a relatively small deterioration to initiate a periglacial regime.

CORRIES AND BLOCKFIELDS

The only discussion of Falkland morphology which had recourse to extensive snowfields was Baker's (1924) theory for the formation of the stoneruns. This required there to be widespread snowfields extending over the whole height range through which stoneruns are found. Frost-riven quartzite blocks from projecting and marginal outcrops were supposed to have slid over these snowfields to produce valley stoneruns. Baker was apparently influenced by the absence of surface interstitial material and by the size of individual blocks (many are several metres in length) to discount Andersson's advocacy of flow-creep and to adopt a theory of rapid slide. No supporting evidence of a snow line to below the present sea level seems to be forthcoming. The implications are unacceptable for they involve the location of nunataks at all altitudes and in all relief situations, while the features expectable from an almost total snow cover, those produced by moving ice, are, by general agreement, absent. Even if snowfields had been associated with rocks sliding down the foot-slopes of individual hill crests the probable result would have been distinct lines of blocks, but coarse ramparts are confined to the corrie and nivation niches in the highest mountains.

There has been a corrie glaciation which affected only the highest hills (Fig. 1). In both East and West Falkland there are two tracts reaching over c. 610 m but the East Falkland tracts are much less extensive than those of the west island. They are both narrow ridges structurally-controlled and approximately parallel to the prevailing winds from the west. The highest (Mt. Usborne) ridge, slightly oblique to the present resultant wind, is sculptured along its north-east lee side into one simple corrie and one compound embayment with three subordinate niches. Small and simple rubble ramparts enclose small lakes. The Wickham Heights have no corries though they are as high as some ridges with corries in West Falkland. Their failure to gather snow appears to have been a consequence of narrowness and unfavourable orientation.

The two West Falkland uplands with corries are round Mt. Adam (c. 700 m) and Mt. Maria (c. 660 m). They are rather similar in extent but significantly different in form. The Mt. Adam block is interrupted by a number of south--north (cross-wind) valleys and the highest ground is on the south. In the Mt. Maria upland the highest ground is in the east and is less cut into by valleys. Both uplands hold well-formed corries and also a number of less-developed nivation niches. All are located in lee positions. The largest occur in the Mt. Maria block, a result of its greater efficiency in accumulating wind-driven snow. Only there do multiple moraine arcs occur.

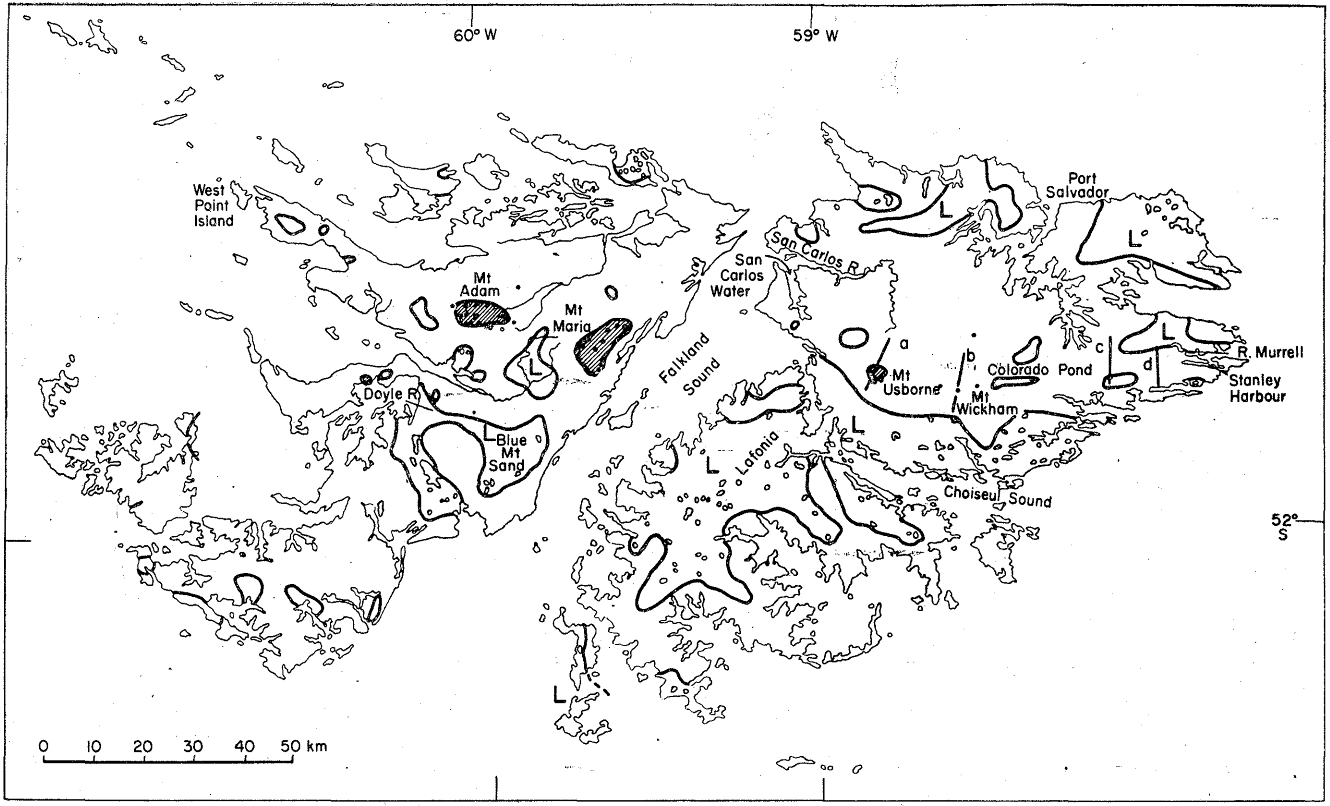


Fig 1. The Falkland Islands

The areas with corrie lakes are shaded. The dots in and near the shaded areas indicate the highest summits. The location of the lines of section in Figure 2 are shown (a, b, c, d). Areas with lakes are enclosed, the major ones being marked L

Corries are found only on ridges over c. 520 m in crest height. The mean height of corrie floors is 450 m, and half are between 400 and 520 m. Central aspect of the corries ranges from 350° to 185°; the mean aspect is due east. This is significantly opposed to the present resultant wind direction, 275°. In present winters when conditions perhaps most closely resemble those of active corrie formation the winds are particularly concentrated in the arc between south-west and west.

A number of corries face north of east; these tend to be located in the higher ground, or to be in the lee of uplands extending the greatest distances upwind, or both. Such locations allowing efficient accumulation of snow favoured its survival in recesses with that aspect.

The large variation in corrie floor altitude in the relatively small number of corries, the small size of many of the corries, the asymmetry of some back walls, and the eccentric location of moraine arcs may indicate the influence of relief and of strong and concentrated winds in accumulating snow below the contemporary regional snow-line, while it is possible that a cloudy climate assisted survival especially in the sun-facing corries.

On Mt. Usborne the compound corrie lies at the back of a major hillside basin which could be interpreted as an older degraded corrie. Trough-like valleys particularly those of the Mt. Adam hills appear to owe their present form to the consequences of severe mechanical weathering and the movement of the associated debris, but the possibility that evidence of an earlier somewhat more extensive glaciation has been largely obscured by more recent processes deserves further examination.

The uplands across and from which snow was driven to accumulate in lee eddies are mantled by blockfields carrying a poor lichen-dominated feldmark vegetation. On these hilltops, similarly in the Wickham Heights, and also on some flat-topped hills such as Mt. Kent (c. 480 m) and Mt. Challenger, the blockfields are autochthonous but vary in character, thin and flaggy on parts of Mt. Adam, rather deeper and frost-sorted on parts of Mt. Usborne. Where the blockfields are highly-developed, as on the highest crests of East Falkland, there are few rock outcrops and these are frost-riven crags surrounded by rubble-mantled altiplanation benches.

The higher parts of the East Falkland uplands have a landscape of more advanced periglacial modelling than is found in the lower eastern hills. Continuous covers of slope debris from summit to valley floor are usual with fewer valley-side outcrops than in the lower eastern and western terminations of the upland (Fig. 2).

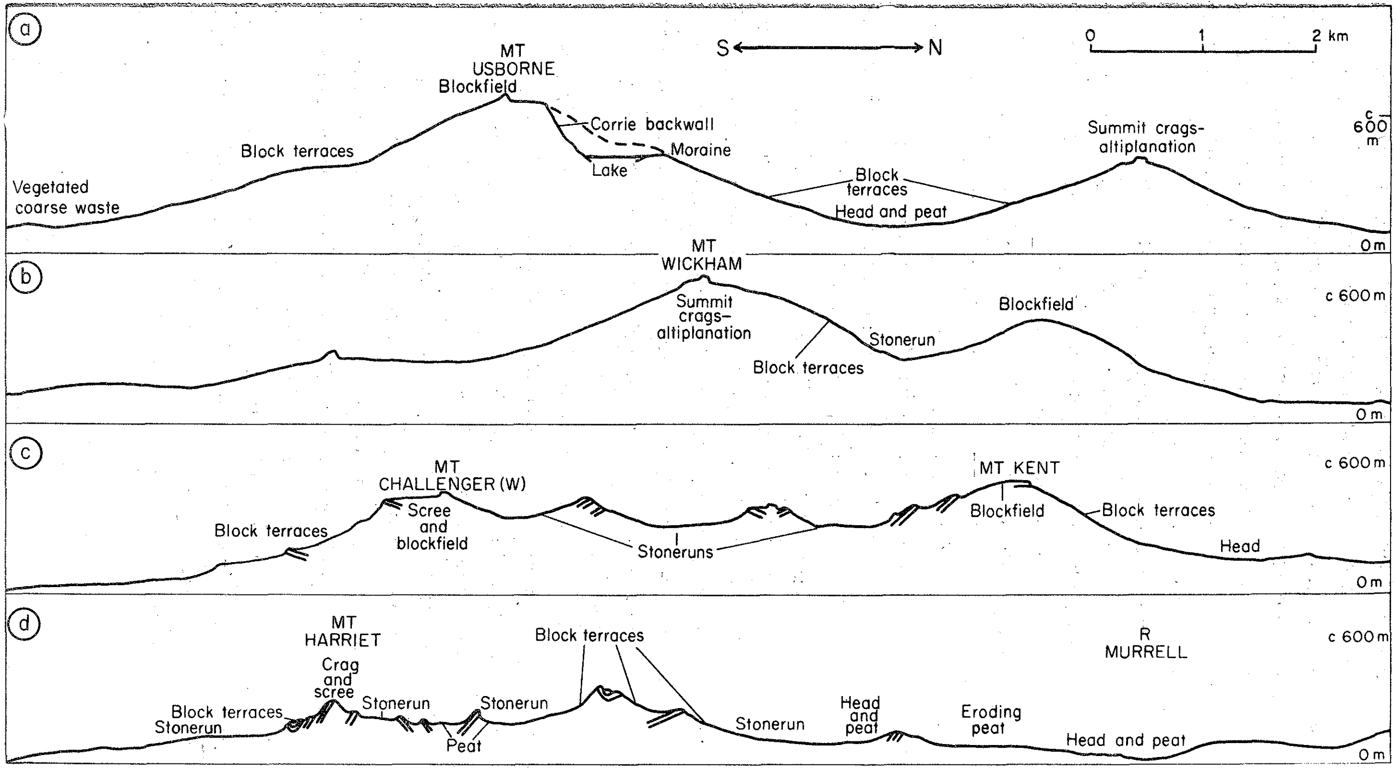


Fig. 2. Sections across the main East Falkland upland

HILLSIDE DEBRIS AND VALLEY BLOCKSTREAMS

Because the East Falkland hilltops preserve only small areas of fairly level ground autochthonous blockfields, though quite well developed, cover relatively small areas. Hillsides within the uplands have a widespread cover of coarse debris derived especially from the ribs of quartzite, some consumed and mantled in their own debris, some still projecting through the mantle. The source of the debris is both hillside and hilltop strata and in places there is a merging of summit blockfield into hillside debris as is particularly well

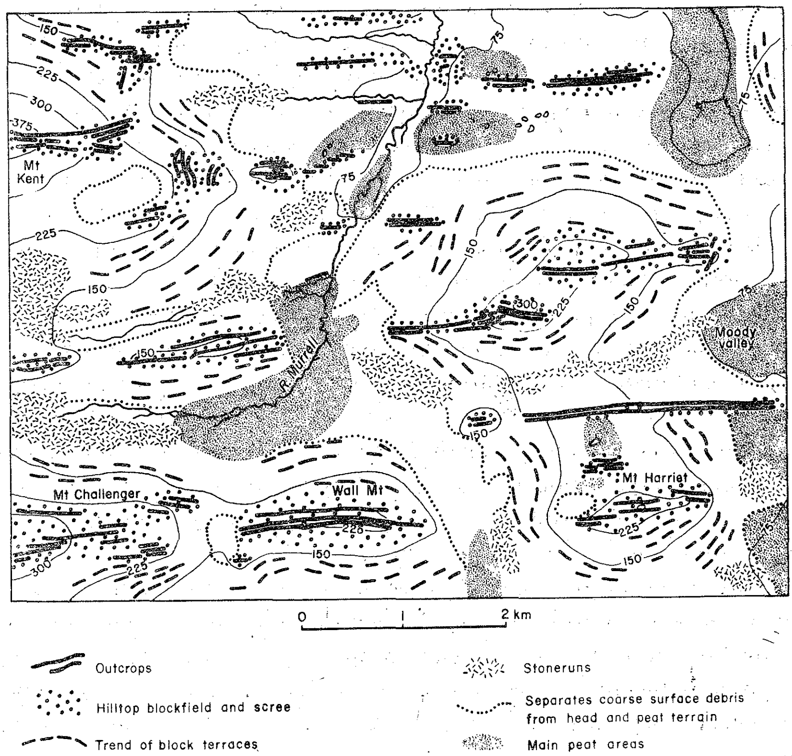


Fig. 3. Features of part of East Falkland

The headwaters of the Murrell river lie between sections c and d of Figure 2. Heights of formlines in metres. Compiled from field observations, ground and air photography, maps C.S.G.S. 4465 (1 : 25 000) and, with permission, D.O.S. 453 (1 : 50 000)

displayed on the flanks of Mt. Usborne. On the lower hills there is frequently a steep talus slope between rock-face and lower debris slope though on dip slopes stripped bedding planes may lead directly on to the gentler-sloping debris cover (Fig. 3).

Much of this debris is composed of boulders which match in size and shape the unmoved joint-bounded blocks in the outcrops. They are dominantly the product of mechanical weathering though in some coarse rather open--textured sandstones there are residual traces of chemical weathering.

It does not appear to have been earlier recorded that many of these hillside debris sheets are organised into block-terraces. Though debris extends below sea level the terraces are most concentrated in the height range 60–450 m on slopes of all aspects. They occur in West Falkland and throughout the East Falkland uplands. Most of the slopes on which they are found have an angle of between 8° and 12°. The lower margins of individual terraces are steep convex slopes in which the boulders often assume a steep, upslope packing. Here and there the convexity become a recognisable bulge across the lower ground. In most cases these terraces cross the hillsides, some with rather simple straight lower edges, some lobate and compound. Where a hillside has dispersed sources of debris the pattern becomes less regular. Generally the terraces follow the contour or are slightly oblique to it. Many of them are very large, particularly in the Mt. Wickham area where a 9° slope of c. 900 m lateral extent is organised into five major terraces. The slope rising west from Colorado Pond displays terraces particularly well.

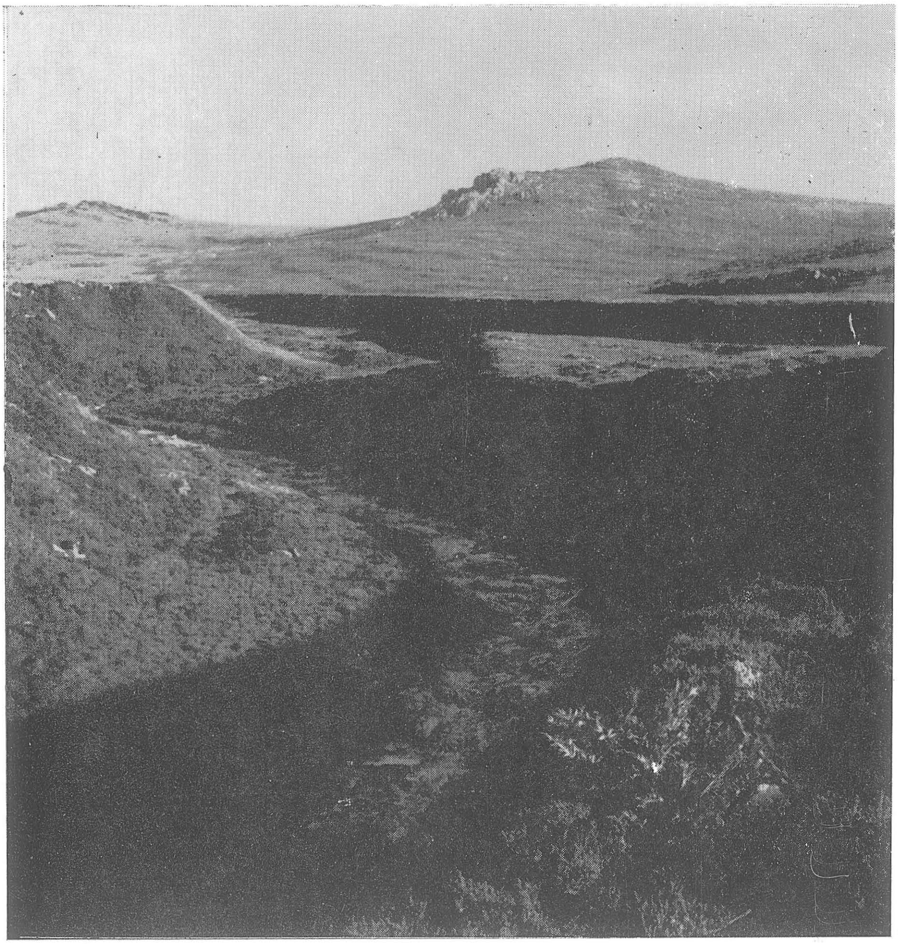
These features appear to be of similar character to those described from localities which earlier had experienced cold climates, e.g. by Benedict (1966) from the Colorado Rocky Mountains and for which a severe periglacial climate was advocated. There is in East Falkland a less obvious relationship to lee areas of snow accumulation than Benedict described. Falkland terraces are frequently larger than those described by Benedict and those discussed by Galloway (1961) from the Scottish Highlands where three metre rises of the front were found.

On Mt. Usborne the long northern slope shows interesting interruptions to the terraces in the form of irregular depressions, some discontinuous, which pass down the slope. From their relationship to the terraces they do not appear to be younger but to have been a contemporary, possibly late contemporary, development. They start below the high shelf and the corries near the mountain top and they may have been caused by meltwater from large snowfields passing over and through the terrace material in integrated flow, hastening the melt of internal ice, the washing out of finer material, and the lowering of specific paths across the terraces.

The surface of the debris mantle is generally coarse with large interstices and little if any fine material. It is possible that some internal sorting has taken place and this will be discussed below.

For a great deal of the extent of their lower margins the spreads of hillside debris give way to blockstreams, stonerivers, or stoneruns. It is these which

Pl. 1. Residual core of quartzite anticline c. 25 m high. Locality is between Wall Mountain and Mt. Challenger (see Fig. 3)



Pl. 2. Valley cut into level distal end of stonerun. Background hillsides crossed by block terraces and broken by outcrops. Locality is south of Port Salvador and west of section C (Fig. 2)

Pl. 3. Lowland landscape of East Falkland. Air view of San Carlos River

have for so long attracted attention. Now the recognition of equivalent landforms in both northern and southern hemispheres means that the Falkland stoneruns must be regarded only as outstanding examples of this class of feature. Essentially a Falkland stonerun is an area of quartzite boulders lacking vegetation other than lichens. The boulders, many several metres in length, are similar to those in the hillside block terraces and also match the joint-determined blocks of the quartzite outcrops. A major distinction between the hillside and the stoneruns is that in the stoneruns although the detail of the surface is very irregular the surfaces tangential to the highest boulders are quite smooth. There appear to be many more perched or unbalanced boulders in the runs than in the terraces.

Joyce (1950) remarked that earlier considerations of stoneruns had concentrated upon those along the strike valleys but added that the runs passed completely over some rounded hills. It is true that debris covers do so extend but it is probable that Joyce did not distinguish between stoneruns and hilltop autochthonous blockfields. He also thought that block detachment did not occur on dip slopes and that this accounted for the absence of runs on the southern flank of the main E. Falkland upland. However, the observation is in error for runs do occur on the southern flank which is not, as Joyce believed, entirely a dip slope. Moreover, within the hills block detachment from dip slopes is a common occurrence.

The material which makes up the runs is more extensive than at first appears for in places it passes beneath present sea-level and is locally concealed under heathland vegetation. In longitudinal valleys the axial gradients of stoneruns may be as little as 1° while lateral gradients are commonly in the range 6°–8°. The largest unvegetated patches are up to c. 5 km long.

Even where the stoneruns extend over saddles they are overlooked by higher ground. While they generally give way at their upper margin to debris organised into terraces elsewhere they originate directly from talus slopes. On some hills, as on the south face of Mt. William, near the head of Stanley Harbour, there is a continuous suite, from opened joints, slightly-dislodged blocks, collapsed blocks lying against the cliff, to a stream of blocks, leading across the talus slope to the stonerun. In such a case it is incontrovertible that boulders on the stonerun are derived from the adjacent outcrop.

Some earlier descriptions, influenced perhaps by the sound of water moving below the coarse blocks, infer a great depth to the runs. Excavation is hardly practicable, but one natural exposure south of Port Salvador disclosed a small depth, c. 2.5 m. Much of this was formed by an upper layer one or two boulders in depth, lacking any inclusions of finer material. Below this were angular cobbles overlying grit, sand and silty mud. The large boulders lie on rather than in the less coarse material. The noise of internal water has suggested that much fine material has been washed out from the runs but at present sufficiently concentrated and powerful flow for this to occur is not usual except at the lower end of some runs in major valleys.

Evidence that water has passed over the surface of stoneruns has not previously been presented. However, south of Port Salvador a large run has a broad central tract of boulders rounded by water erosion but now lichen covered. The channel width is much more than would be expected for normal run-off. This may be associated with an excessively wet period since the runs were formed, or with rapid melt of surface snow and ice required to flow over the surface because of internal ice or because of a greater infill of fine material, or with the operation of a combination of such influences.

The debris mantle appears to be stable, frost-riving on cliffs is significant only on the highest hills, much talus is stable, upper surfaces of stones are evenly lichen covered, only in limited areas there are signs in distortions of turf of continuing movement, and the slumped sides of river incisions at the lower margins of some runs appear to be stable. The stoneruns must be regarded as relict or inherited landforms.

Evidence of a true sorting of the debris mantle and the fact that rocking boulders are more numerous in the valley stoneruns than on the hillside debris mantle are of interest. The latter shows signs of downslope movement, while both show evidence of sorting. Coarse debris conceals many of the shale tracts within the hills and it is likely that as the last period of cold climate progressed the coarse material from the quartzites extended itself over the shale areas. Coarse material would trap snow while seasonal surface melt would transfer water and any fine material into the cover. The fine material would become increasingly frost susceptible and with the coarse surface open to snow and rain the likelihood of masses of ground ice forming within would increase. It is possible that weathered shales were in places incorporated in the base of the cover.

The hillside debris represents the material in course of transport down the steeper slopes when the climate ameliorated. The smoother saddle and valley stoneruns represent the material which, already arrived at the foot of the local slope, had become involved in slower movement along valley axes or which had become part of a motionless rock-ice mass in the valleys. Eventually subsidence of the whole by melting of the internal ice let down the surface blocks; some were left in a perched and unstable position from which no subsequent force has dislodged them.

In some areas of restricted occurrence a type of smaller debris terrace is to be found. Such terraces have steep fronts rarely exceeding a metre in height, and more usually about half that. They contain fewer large fragments and a higher proportion of fine material than the larger terraces. In some places their turf cover is discontinuous and in the steeper areas recent tearing appears to indicate some continued movement. These smaller terraces occur where concentrated seepage from upslope sustains saturation. Some of the larger terraces carry smaller ones on their treads: other smaller terraces occur where finer material has accumulated in the niche between hillside debris sheets and stoneruns. These smaller terraces are generally associated with the eluviation of fines from the hillside debris and they are more usually found on lower ground.

The formation of the small terraces was dependent upon the immobilisation of the large, and thus upon climatic change. This involved a great diminution in the rate of physical weathering, the dissipation of snowfields, and the thawing of internal ice.

HEAD AND THERMOKARST

The most usual lower margin of the stoneruns is with little if any change of slope to a cover of yellow-brown head which contains fragments of quartzite. Wide areas in the major valleys and peripheral lowlands are mantled by this fine-textured head of rather variable character. There are many small exposures; the greatest observed thickness was c. 4.5 m. As with some stoneruns this material extends beneath the sea. Where it has been sea-worked the dispersal of the fine matrix has left a 'lag' cover of boulders. The extent of coast formed of head and its presence on outlying islets suggests that major sheets of head have been invaded by a rising sea.

There is evidence that the head is not the result of a single phase of activity. In the area of Murrell River and Stanley Harbour several exposures show interbedding of washed and sorted sands and gravels; there are also thin beds of layered stone-free clays. That the surface of the head has been locally washed is shown by pavements of residual gravels. The occurrence of surface patches of stone-free silts also indicates the wash of finer materials to lower ground. On the coast of San Carlos Water cliffs cut into head disclose that its accumulation has been discontinuous for there are peat layers some metres below the surface. Less conspicuous interbedded organic layers are found on the south shore of Stanley Harbour.

At the east end of this harbour a relationship between soliflual and marine activity can be seen. In one exposure beach and dune sands are covered by a main cobble layer itself covered by earthy head. The main cobble layer merges laterally on the landward side into head; it is at the same height as old cobble ridges on more open shores. The evidence appears to indicate that mobility in head continued into the period when sea levels were well recovered from glacial-eustatic depression. There is similar evidence on the outer coasts south of Stanley Harbour. It seems probable that the locally extensive dune tracts and cobble ridges are due to sorting and inward transport as rising seas concealed and worked the lowest spreads of head and stoneruns.

The surfaces of the head terrain are usually quite smooth, often forming shallow concave hillfoot aprons extending onto flanking lowlands. Locally patches of coarser debris and residual outcrops break through the blankets of head.

Most of the larger streams flow in trenches cut into head. In some places the incisions start at the distal margins of stoneruns and, though the collapsed sides obscure evidence of relationships between stoneruns and sheets of head, the frequent lack of marked slope inflections at the junctions, the coarse material locally lying on the head, and the indication (not conclusively observed) of a merging of materials suggest contemporary origins. Within the head the sides of river trenches are normally vegetated and exposures are few, although south of Mt. William patches of bedded outwash are revealed along stream sides.

Streams crossing the head terrain are generally underfit. Many of them flow on valley fills within larger incisions. Abandoned channels on the present valley floors and on terraces a little above the present channels have a higher capacity than those in present use. Wavelengths of older meanders are up to ten times greater than those of present streams, though in most cases the ratio is closer.

Signs that mobility of head continued until sea levels were recovered from glacio-eustatic depression suggest that heavy loading of streams would also persist. Some streams still mobilise large loads at times of peak discharge, but the overwhelming evidence is of more shifting and less-defined courses, heavier loading, and higher peak discharges in the past. Many of the small first--order lowland streams follow primary irregularities on the blanket of head. The major changes in discharge characteristics which are indicated by the stream and valley forms appear to have taken place after the incisions attained their present depth or almost so. It seems that the change in behaviour was relatively late, when sea level recovery was advanced and head mobility became much reduced.

Within the Falklands there are innumerable lakes. Many of these are coastal lagoons or disused stretches of river channel. There are also some sixteen corrie lakes (Fig. 1). Many lakes occur among the spreads of thick peat; these may be of more than one sort for there is evidence of wind erosion and of peat flows producing hollows in the peat. There are also on smooth peat-mantled interfluves and low tablelands some regular and almost circular lakes which are unexplained but which may reflect irregularities in the sub--peat surface (often of head).

Some lakes occur within coarse head, stone-run, and block-field material in plateau, valley, and hilltop locations. In examined members of this class it has been difficult to determine origin and it may be that there is no single mode of origin. Possible contributions may come from variations in the thickness and surface form of the superficial material, as when a major path of debris movement crosses or deflects a minor one, from variation in the internal composition of waste-mantle, from variation in the accumulation of internal ice and subsequent differences in surface form consequent upon thawing.

Many lowland areas contain lakes, particularly in the Lafonia area towards its north and west, and round Choiseul Sound. North of Choiseul Sound the structural grain of the country runs at approximately 115°. In the lowland below c. 60 m this lineation influences the shapes of the larger lakes confined between parallel upstanding ridges. The structural strike direction is very similar to the direction of dominant winds and the long axes of many of the lakes are the result of the two influences operating substantially in harmony. The Choiseul Sound lakes vary in longest dimension between 0.05 km and 3.0 km with an overall decline in frequency with increase in size, broken by intermediate frequency peaks at 0.65 km and 0.85 km. The median value is 0.35 km. The lakes were perhaps initiated round the nuclei of ice thawing within head. The minimum figures probably relate to the present sizes of uncoalesced thaw depressions and the higher figures to their amalgamation.

It is notable that the local coastline includes stretches which reproduce the characteristic outline of the lakes. These coastal bays are within the same size range. It is likely that the sea's advance over a head terrain which had lost permafrost and developed thaw lakes caused these coastal features. There are other more restricted areas which carry lakes and marshes, often elliptical in outline. These lakes are smaller and less numerous than in the Choiseul Sound–Lafonia areas.

North of the Wickham Heights there is a tendency for lakes to be absent from the very lowest ground including the very lowest riverside land bearing traces of shifting channels. This feature of distribution was also noted from the interior of Alaska where it is perhaps related to a reduced development of deeply frozen ground near rivers (Cailleux, 1967), but this characteristic is not found in all Falkland localities.

There are areas on West Falkland that have a high density of small lakes, the low flats of the Doyle River up to 60 m altitude, and the higher Blue Mountain Sand district. Parts of these areas have surface gradients of less than 1°. The range of lake size is here more restricted, up to 0.7 km from 0.05 km with the median values of longest dimension c. 0.2 km in one group and less than 0.1 km in others. Lake and pool densities in excess of 100 lakes/km^2 are found.

Many of the lakes have clearly distinguished longer axes. In the lower Doyle area the longer axes (though the ratio of longer to shorter is not great) show a marked parallelism which is almost precisely normal to the resultant and the dominant wind direction. On the downwind eastern shores shelving beaches are of frequent occurrence. These lakes appear to have responded in a similar way to Alaskan thaw lakes described by Carson and Hussey (1962) who in a study of such a parallelism concluded that the growth of beaches eventually insulated permafrost and inhibited wave action up and down wind promoting a subsequent crosswind extension. Many of the larger lakes of the Doyle area show a lobate outline clearly due to the coalescence of smaller lakes, and it is apparent that growth and conjunction have been in a crosswind direction. There are also drained lake beds of similar shape.

Few of these lakes are incorporated into the surface drainage systems of their areas, being avoided by streams, many of which have curved reaches concentric to the lake shores. Narrow damp depressions, chains of pools, and also peripheral ridges show similar curvilinear patterns. This combination of features has been suggested as diagnostic of degraded pingos and it thus seems that many of the lakes in these lake-fields occupy sites of pingos. Many of them very closely resemble the Alaskan thawed pingos as, for example, described by Cailleux (1967). In the superficial materials among the lakes there are surface markings of reticulate and polygonal pattern. These also occur in patches near the mouth of the R. San Carlos and are the surface expressions of ice-wedge pseudomorphs. The hydrological patterns of these lake areas seem to have a strong resemblance to those of the North American arctic coastal plain (Mackay, 1963; Carson and Hussey, 1962).

LANDFORMS AND CLIMATE

From the highest summits to below present sea-level there are landforms and materials which are the products of severely cold and ameliorating climates. These have been significantly modified only by the encroachment of the sea and obscured only the growth of peat and vegetation. This suite itself modifies but does not conceal an earlier landscape which is characterised by a series of generally level surfaces truncating structures and related to a series of higher base levels.

The nature of the association of cold climate landforms is clear and the relationships between weathering, erosion, and deposition consistent. In its overall character major parts of the Falklands and especially the uplands present periglacial landscapes. In the higher uplands particularly round Mts. Usborne and Wickham the development of this landscape is well advanced in that slopes mantled with waste largely hide the details of underlying structure which are so prominent in the lower hills, and rock outcrops form a much smaller part of that area than in the lower hills.

The major classes of landforms and materials of periglacial character have been described in a progression – blockfields and corries, hillside debris and valley blockstream, head and thermokarst features. This appears to be a useful order to apply to the local landscape. It follows the gravitational path of weathered material and leads from areas of greater erosion to lower areas characterised by accumulation.

Althought there is evidence of fluctuations or stages within the period of climatic deterioration there is not yet a detailed chronology and the present description is in general terms. However, there may be areas where a more complete sequence of evidence has survived and in this respect it may be noted that the coastal West Point Island forest bed has not yet been conclusively investigated. The presence of trees now found in Chile in more northerly latitudes, of conifer pollens, and the nature of the containing material deserve more attention.

Other materials suitable for detailed investigation occur in addition to the thick peat covers of the poorly-drained lowland areas. Included are the trees stranded in isolated coastal lagoons and behind cobble beaches at the eastern end of the group. These, apparently drifted in at a time of high sea level, may prove to be associated with the Shell Point, Port Fiztroy (south of Mt. Challenger) 6 m beach and littoral fauna (Adie, 1953). The peats found below high tide level near Stanley, and those interbedded in blown sand and in head, should prove of value in elucidating the details of past climates, as might the washed and bedded material in the head.

The full degree of climatic deterioration associated with the suite of cold climate landforms is of major interest. Some coarse, stony ramparts enclosing corrie tarns show the effect of frost sorting, and stone stripes are found down to an altitude of about 400 m in some of the coarse debris which mantles smoothly convex hilltops. These are not of the type requiring severely frozen ground. They do show that at least seasonal cold persisted or returned after the complete development of the moraine arcs. Although it has already been suggested that the corrie and nivation hollows do not permit assessment of a regional snowline, they clearly tell of its considerable depression. The changes in precipitation and temperature responsible for this require discussion. It is clear that there is a relationship between the location of the corries and the vast blockfields of the highest uplands. The sweeping of snow into the corries would reduce the snow cover which might have protected the bedrock from severe frost action. Thus they can be regarded as genetically associated. However, it is not clear whether maximum cold coincided with maximum snow-

-line lowering; that is, when the relationship between cooling and precipitation most favourable for snow accumulation took place. The lack of more widespread evidence of snow accumulation and glaciers suggests that snow falls were generally low.

Various features of the landscape appear to have needed permafrost for their formation and this would require a mean annual temperature of 6°–7°C less than that of the present. Péwé (1966) has given evidence that for the development of thermal contraction cracks even greater cold is needed, with mean annual temperatures about –6° to –8°C. Application of these figures to the Falklands despite doubts about their validity (Schenk, 1967) would signify a mean annual temperature at present sea level 12° to 15°C less than now experienced. The lower of these figures is not dissimilar to the reduction suggested for corresponding European latitudes (Wright, 1961; Shotton, 1962; Hoppe, 1963) and at the lower limit of the range of difference Péwé thought would be required for central Europe and central England to explain the presence of similar features. Heusser (1966) has recently given reasons for accepting a broad harmony for Northern and Southern Hemisphere climatic fluctuations in the Late- and Post-glacial periods, and it is reasonable to assume that the Falkland evidence of severe cold would correlate with parts of the Vistulian of the Northern Hemisphere.

The influence of the global climatic change upon the regional climatic situation is important. The eustatic fall in sea level of the Vistulian glaciation would enlarge the land area of the Falklands considerably. From various published estimates a conservative value of 90–100 m is here used as the difference between the Vistulian low level and present level to assess this expansion. Valley systems can be traced down to about 45 m below present sea level, well within the overall withdrawal. The effect would have been slight in the south-west where deep water reaches close to the present shore, and greatest to the north where a tract at least 32 km wide would have been exposed. To the east, close to the edge of the continental shelf, a zone 8–27 km in width would have been exposed. A land area exceeding at least 120 km longitudinally would have existed. The ensuing decrease in oceanic climatic characteristics would be further enhanced by exposure of the shelf along the Patagonian side. A reduction in maritime modification of air passing east towards the islands from South America could be expected. Development of the Andean ice cap would further cool and dry air coming from the Pacific. Clearly the reduced passage west of the Falklands would be occupied by water considerably cooler, chilled by ice from the Fuegian region. Joyce (1950), to account for the tundra climate which he considered necessary for the development of stoneruns, suggested that the Antarctic Convergence moved north. At present the Convergence reaches latitudes lower than those of the Falklands but farther to the east, South Georgia being on the polar side, and now having a mean east coast temperature some 3°C lower than at the Falklands. The inclusion of the Falklands within the Convergence might depend on the position of the Convergence in the Drake Strait, for if sub--Antarctic surface water were excluded from the Fuegian zone, the Falkland seas might then be wholly of Antarctic surface water about 4°C colder and capable of carrying pack ice and bergs to much lower latitudes. Clearly such a fall in ocean temperature would be only partly competent to cool the area to the extent which morphological evidence demands. The local terrestrial heat balance and the decreased modification of Antarctic air in its passage north over the sea would be important. The greater frequency of advection of this cold air together with reduced opportunity for basal warming would contribute to greater cooling.

It is interesting to consider the potential influence of those conditions on precipitation. At present there is a slight winter rainfall minimum associated with lower falls per rain-day, and there is some evidence that this is in part due to development of summer convectional showers. At Stanley the mean annual precipitation is about 680 mm and over much of the archipelago mean annual precipitation probably varies between less than 400 mm in the low southeast and over 700 mm in the main uplands. It is likely that under conditions of extreme cold such mean annual totals would not be achieved, due to the greater regional continentality, both from larger areas of land and from pack ice. It is also likely that these circumstances would sustain summer maximum characteristics contributing to the wetness of thawed layers but not increasing the opportunity for snow accumulation. It has already been noted that the location of the corries indicates the prevalence of westerly winds during the period of their growth, and the shape of many small lakes shows that these winds dominated during the period of their development.

References

Adie, R. J., 1953 – New Evidence of Sea-level Change in the Falkland Islands. *Falkland Islands Dependencies Survey Scientific Reports* No. 9; London.

Andersson, J. G., 1906 – Solifluction, a component of subaerial denudation. *Jour. Geol.*, vol. 14.

Andersson, J. G., 1907 – Contributions to the Geology of the Falkland Islands. *Wiss. Ergbn. der Schwed. Südpolar Expedition, 1901–3*, Bd. 111; Stockholm.

Baker, H. A. 1924 – Final Report on Geological Investigation in the Falkland Islands, 1920–*2*. C.S.O., Stanley.

Benedict, J. B., 1966 – Radiocarbon Dates from a Stone-banked Terrace in the Colorado Rocky Mountains, U.S.A. *Geografiska Annaler*, vol. 48, A/1; p. 24-31.

Cailleux, A., 1967 – Actions de vent et du froid entre le Yukon et Anchorage, Alaska. *Geografiska Annaler*, vol. 49, A/2–4; p. 145–154.

Carson, C. E. and Hussey, K. M., 1962 – The oriented lakes of arctic Alaska. *Jour. Geol.*, vol. 70; p. 417–439.

Galloway, R. W., 1961 – Solifluction in Scotland. *Scottish Geog. Magazine*, vol. 77.

Heusser, C. J., 1966 – Polar hemisphere correlation; palynological evidence from Chile and the Pacific north-west of America. *In:* World Climate from 8,000 to 0 B.C. *Royal Meteorological Society, Symposium Proceedings;* p. 124–141.

Hoppe, G., 1963 – Some comments on the 'ice-free refugia' of northern Scandinavia. *In*: 'North Atlantic Biota and their History'. eds. A. Love and D. Love.

Joyce, J. R. F., 1950 – Stone Runs of the Falkland Islands. *Geol. Magazine*, vol. 87; p. 105–115.

Mackay, J. R., 1963 – The Mackensie Delta area, Northwest Territories (Canada). *Can. Dept. Mines, Tech. Surv., Can. Geographical Branch*, Mem. 8; 202 p.

Péwé, T. L., 1966 – Paleoclimatic significance of fossil ice wedges. *Biuletyn Peryglacjalny* no. 15.

Schenk, E., 1968 – Fundamental Processes of Freezing and Thawing in Relation to the Development of Permafrost. *In*: Arctic and Alpine Environments, eds. H. E. Wright and W. H. Osburn, Indiana U. P., Bloomington.

Shotton, F. W., 1962 – The physical background of Britain in the Pleistocene. *Advancement of Science*, 19; p. 193–206; London.

Wright, H. E., 1961 – Late Pleistocene Climate of Europe. A Review. *Geol. Soc. America, Bull.*, vol. 72.