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SUBJECT :

"STONE RUNS OF THE FALKLAND ISLANDS"

by
J. R. F. JOYCE.

CONNECTED FILES.

NUMBER AND YEAR.	
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STONE RUNS

of the

FALKLAND ISLANDS.

J.R.F. Joyce.

Since the earliest published descriptions the stone runs of the Falkland Islands have been a source of interest and speculation to geologists and physical geographers. When Andersson proposed the Solifluction Theory of their origin the matter seemed closed, for this theory has been generally accepted as satisfactorily accounting for their formation. Unfortunately the Falkland Islands are remote and little visited by scientific personel, who have the time and opportunity to study the phenomena. This paper is based on studies of the stone runs of East Falkland. There was no opportunity to visit West Falkland, but Falkland Islanders who could speak from personal knowledge were questioned as to the localities where the runs occurred. Their answers were collated and recorded on the Admiralty Chart which is the only map available. The time now seems opportune to bring to notice some serious objections to Andersson's theory and provide a further explanation.

No observer attempted either a scientific description or an explanation until Darwin published his excellent account of the stone "river" at the head of Berkeley Sound. This was to him so awe-inspiring that he invoked the agency of a catastrophic earthquake as the explanation. It was left to Wyville Thompson to suggest something nearer the truth when he said that many factors took part in their formation. He selected alternate drying and saturation and vegetable decay as causing hill creep which he took to be the transporting agent. From Darwin's and Thompson's descriptions James Geikie suggested that the stone runs were comparable to the rubble drift of southern England and that they are essentially a product of tundraic conditions where "freeze and thaw" attain maximum effect. Andersson (14-2) carefully studied the suggestions made by these authorities and incorporated such of their ideas as seemed to him sound in his paper. He made a most painstaking scientific study and map of the stone "river" described by Darwin.

Darwin selected for his description the stone run most like a river; had Andersson[2] selected a less river-like example in another area he might have had cause to modify his ideas considerably. Andersson[1] proposed that the stone "rivers" are caused by the flow of supersaturated soils which bore with them the stone blocks. This process he says is still operative in the Falklands and he shows a photograph of a present-day mud flow at Port Stevens on West Falkland. Baker, unable to find himself in agreement with Andersson, postulated local ice caps with quartzite ridges as nunataks. From these nunataks he says frost action detached large blocks which "slithered down the icy slopes".

Taking the stone runs as a whole there is some truth in each of the above mentioned theories but no single one will account for the whole process. Since Andersson took careful account of all the previous work this discussion can profitably begin with his theory.

Andersson, in describing the modern mud flows, admits that they are smaller than those necessary to produce the Darwin stone "river", and further that they only occur where the slopes are steeper than they are at the head of Berkeley Sound, and where vegetation is scarce and trickling water has saturated a section of this steep slope. He compares the Falkland Islands with other areas where this is operating, and rightly concludes that solifluction can mostly be expected where tundraic conditions have existed for a considerable time. (Note A). He also recognises that the stone runs of the Falklands have a greater extent than is at present exposed as they are masked by vegetation.

Note A. At some risk of being taken to task by climatologists I propose using the adjective tundraic, using it essentially to denote the effect of tundra-climate temperature-changes ("freeze-thaw" phenomena) irrespective of questions concerning precipitation amounts, although I am aware that the tundra is a continental feature.

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His theory of the formation of the stone runs can be criticised in the following argument. Not all stone runs lie progressively downhill; there are some notable examples which lie across the tops of low dome-like hills. This feature is most noticeable where the dips of the underlying rocks are low. On the boundary of the Devono-Carb Series and the Lafonian Series no stone run flows over the Lafonian. Since the Wickham Heights, which overlook the Lafonian are the highest range on the Islands, it is here that one would expect the greatest development of the stone runs. This is not the case. The material of the stone runs is always quartzite obviously parted on the jointing and bedding planes and the blocks can attain in many instances considerable size. Some measured on the Moddy Valley stone run are estimated to contain more than 40 tons in a single block. Such blocks would surely have sunk under Stoke's law to the bottom of any viscous mass more rapidly than they could have been transported laterally. Further they are so numerous that they would have soon jammed immovably on the gentle slopes where friction and the gravitational forces exerted on each block would have been greater than the force exerted by gravity on the moving/mass of soil. No section of a stone run from the surface to the soil is available for examination, but all writers are agreed by implication that they are of considerable thickness. How the required thickness of soil necessary to transport such a volume of stone could have accumulated during the time tundraic conditions were existing is difficult to imagine. If mud flows had accounted for the movement of the blocks, it is certain that not everywhere would the flows have taken place at the same time. Thus overlapping of the flows would have taken place. Present day mud flows have a typical form as is shown by a very recent one seen in Deception Island. Photograph 1. The flow is small but nevertheless it must illustrate the action of larger flows. The photograph shows: the steepness of the slope from which the flow came, the checking of the flow as soon as the grade is reduced, and the peculiar "mine-tip" appearance of the moved material. The transportation of moderately large sized blocks for short distances is also illustrated. It is believed that the reduction of the grade was not the only factor which brought the flow to a standstill. On the distal and lateral sides of the flow there were erosion gullies, which are evidence that flow by its movement drained itself. By this reduction of water content the flow became too viscous for mobility. Mud flows must drain too rapidly to flow for several miles over slight slopes even if we postulate an annual movement under "freeze and thaw" conditions. On some slopes the sheets of stones are continuous. On others it is not difficult , nor beyond the bounds of possibility, that the boulders exist over large areas which are now masked by vegetation. Indeed the hummocky surface and isolated exposed boulders provide definite evidence for this belief.

For a complete understanding of the stone runs of the Falklands some account of the general geology of the area is necessary, since their origin appears to be connected with the tectonics and the lithology, and perhaps most particularly with the Antarctic glaciation.

The succession of the rocks has been worked out by Andersson[2], Halle and Baker as being:-

Lafonian (Gondwana)	Upper Series	Upper part Lower part
	Lower Series	Lafonian sandstones Lafonian Tillite
	Unconformity	
Devono-Carb	Upper Quartzite Series Marine Devonian Series Lower Devonian Series	
	Unconformity	
Archean	Cape Meredith Series	

The distribution of these rocks according to these authorities with the addition of recent information is shown on the Lithology map (Map 1). Observations on East Falkland show that stone runs are confined within the boundaries of the Upper Quartzite Series. The plotted occurrences from West Falkland confirm this. Stone runs, for reasons which will be shown, are not everywhere found within these boundaries.

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The tectonic pattern of the Falklands is not known in great detail, because adequate topographical maps are lacking. Whether or not there is much faulting and overthrusting cannot be discussed here, but the distinct rucking between the tectonic lines at the north end of Falkland Sound can scarcely have occurred without some enormous accommodation in the rocks. At the least strike faulting seems probable. The main tectonic trends are shown on Map 2. Over the main outcrop of the Quartzite Series on East Falkland the structure is that of a sharply folded anticlinorium with a distinct suggestion of some strike faulting. The individual folds in the anticlinorium are of small amplitude especially where the quartzite bands are thin. In the field, rocks can be seen dipping to both flanks of the anticlinorial axis. In the centre the dips are high becoming much lower towards the north than they are on the south side of the axis. The sections on Illustration 1 demonstrate this.

Within the Quartzite Series, the two main rock types are quartzites and shales. Some of the quartzites appear in hand specimen to be fairly well recrystallised, while others have the appearance of being siliceous sandstones. Between these two types there are all gradations. Where the quartzites are sharply folded saddle-shaped vugs have opened on the bedding planes at the crowns of the folds. Quartz crystals have been deposited in these vugs. In vugs exposed in dissected anticlines quartz crystals can be found lying loose and separated. Here is an easy road for attack by frost [redacted] action due to ice formation in the [redacted] partings in the solid quartzites. The shales, both within the Quartzite Series and within the Marine Devonian, show a cleavage lying at variable angles to the laminations. The angles appear to vary with the intensity of the folding. The cleavage causes the shales to break very readily into trapezohedral fragments often less than an inch and rarely more than a few inches in length. The fragments are often highly iron-stained and as the shale is fairly rich in pyrites it weathers easily.

In the Islands, as remarked by Andersson, evidence of glaciation is entirely lacking. There are no ice moulded forms, striations, roches moutonees, moraines or tills. A few erratics, however, are found but these are confined to the shores and may be explained as having been transported by ice rafts. There is no evidence that the Antarctic Ice ever reached South America as the glaciation there was only an advance of the Andean Ice caps; and, indeed, it seems clear that the Falkland Islands also escaped glaciation in Pleistocene times. The maximum advance as suggested by Flint is shown on Map 3. (Note B.)

Further there is no evidence in the geology to relate this advance with that of the Northern Hemisphere although Caldenius attempts to place the South American Glaciation on the De Geer Swedish Time Scale. Simpson would make them contemporaneous, and Milankovitch considers them slightly dis-synchronous, while Brooks (2) thinks they are without any relation to each other. Although the tempering effect of the South Atlantic and South Pacific Water masses prevented the Antarctic Ice from reaching the Falklands the climate of the Islands must have been more rigorous than that of today.

The following table provides some interesting comparisons.

Note B. The form of the west coast of South America, south of Lat.42°S. (i.e. the most northerly point where the glaciation reached sea level) contrasts strongly with that north of 42°S. I can find no reference to it in the literature but I am strongly tempted to compare it with the west coast of Grahamland as described by Holtedahl.

TEMP. MEANS	LATITUDE 50°S. (sea average)	FALKLANDS	SOUTH GEORGIA	BEAR ISLAND
Yearly	41.9°	42.8°	37.8°	29°
Maximum Monthly	46.9° (Jan.)	49.3° (Jan.)	43.5° (Feb.)	41° (Aug.)
Minimum Monthly	37.4° (July)	36.7° (July)	27.9° (July)	17° (Mar.)
Range	9.5°	12.6°	15.6°	24°

Notes:-

(1) All temperatures in degrees fahrenheit.

(2) Falklands Station is Cape Pembroke; (data from Brooks).

(3) South Georgia Station is Grytviken; (data from Brooks).

(4) Bear Island quoted from M.O.4466(7), vol.11, pt.7, 1941.

(5) Lat.50°S. quoted from Meinardus.

(6) South Georgia has three months with the average temp. below 32°F.

(7) Bear Island has seven months with the average temp. below 32°F.

The table shows just how little the Falkland Islands climate of today would have to deteriorate to produce conditions of "freeze and thaw". The amount is not outside that probably caused by the adavncé of Antarctic Glaciation. This advance must have pushed the Antarctic Convergence further to the north than it is today. At the present time the Falklands lie between the extreme and average limits of drift ice as is shown on Map 3. The probability is that they then lay between the average limit of drift ice and the edge of the pack. How near they lay to the edge of the pack is a mater of speculation (Note C.). It is probable that the large water masses, circumpolar currents, and prevailing

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Note C. In the hope that information on this score might be deduced from ice rafted erratics, I searched the literature for records. There are none but surely here is a useful line of research.

Especially on the east coast of South America.

winds would effectively disperse the ice long before the latitudes of the Falklands were reached. What however seems a reasonable assumption is that the waters of the Falklands in those times were often quite polar because of the increased quantity of drift ice. At the same time the polar front must have been further north bringing the Falkland Islands more and more often into the region of cold air behind the front than it does today. When more is known about the peats, the soils, the raised beach deposits and the West Point Island Forest Bed this past climate may be less of a matter of speculation.

The preceding argument provides evidence for the main causes of the formation of the stone runs. To picture the method of formation is not difficult when we remember firstly the rock series composed of contrasting quartzites resistant jointed and bedded, and the shales, easily weathered and already in small trapezohedral fragments; secondly, the small sharp composite folds of the anticlinorium and thirdly a possibly long period of tundraic or near tundraic climate.

If the climate was tundraic "freeze and thaw" would be operating at its maximum, and as a consequence the quartzites and shales would show differential disintegration. The quartzites not being readily subject to weathering and being almost homogeneous would only be affected along the major jointing and bedding planes which were already opened by the folding for the attack by frost (already mentioned on p.5). Because of the frequency of the individual folds at least near the axis of the anticlinorium the attack would take place at many points at the same time. The shale already in small fragments would, in addition to frost action, show some katamorphism. The fine material from this would be removed rapidly by "freeze and thaw" action. The proportions of quartzite to shale are not known, because of the poor exposures due to masking by peat, but it is believed that the shales are subordinate. Where shales underlie the quartzites, there would be a progressive undercutting and the frost-parted blocks would in the course of time be detached from the scarps. The blocks would remain almost in the position where they fell and thus would carpet the area over which the scarps retreated. The size of the blocks would be almost entirely controlled by the disposition of the jointing and bedding planes, since frost shattering would have little effect on such a homogeneous material as quartzite except where it could penetrate into fractures and partings. On the dip slopes there would be no detachment of the quartzite as is shown on Illustration 2A. and, where the dips are small and folding gentle, there would similarly be no breaking up of the strata. This would account for the areas within the Upper Quartzite boundaries, which are free from stone runs. As for the stone runs which lie across the tops of gentle slopes, several dispositions of the strata could account for the occurrence. In Illustration 2B the case of a gentle syncline has been shown.

Where the blocks are of widely assorted sizes or are more uniformly of smaller size it is not difficult to imagine fine material trapped between the blocks, finally leading to the establishment of soils and vegetation. Where the jointing and bedding provided large blocks, the gaps between the blocks were so large that the fine material could not be trapped. Where the stone runs were of greater thickness, vegetation was unable to establish itself owing to lack of light so that even this agent was unable to assist in the trapping of fine material. There has, in effect, never been any vegetation over these areas, which form the almost unique stone runs of the Falkland Islands.

There is some truth in Wyville Thompson's theory of hill creep since the blocks must have moved short distances in settling down. Geikie's "freeze and thaw" theory would account for the detatchment of the blocks and the removal of the finer products of disintegration. Solifluction, while admittedly a powerful agent of sub-aerial denudation, cannot explain those stone runs which cross the tops of hills. A mud flow sufficiently large and powerful to move millions of tons of rock over four kilometers down grades of a few percent requires some corroborative evidence by solifluction in action today. Had it played even a major part in the formation of the stone runs, overlapping of deposits, crude stratification of the deposits, or even ploughing back of previously formed deposits would have been seen. Solifluction played its part, but in a minor role to that assigned to it by Andersson. If the colder period was of sufficient intensity to form cyclic ice, then Baker's picture of the quartzite nunataks being exposed to intense frost action will be true, but the detached blocks will not as he supposed have "slithered down the icy slopes". To those factors another of powerful local action should be added, namely, frost heaving, which may possibly account for some of the upended blocks figured by Andersson.

The stone runs of the Falkland Islands beside being of scientific interest have an economic aspect not generally recognised. Today, when horses are the main means of transport between the sheep stations, they can be a serious bar to communications where they necessitate long detours. They will also make the construction of roads costly. For the same reason they will make the finding of a site for any proposed aerodrome near Port Stanley difficult. At present those parts of the stone runs which are devoid of vegetation sterilise a greater part of the upper quartzite outcrop than is realised. On sheet 1B of the 1:25,000 G.S.G.S. Map No.4456 of the Falkland Islands 17.8% of the outcrop of the Upper Quartzite Series is barren of vegetation. For East Falkland the figure is probably as high as 15%. No estimate can be given for West Falkland. None of these considerations is, however, serious when compared with the following effect. The soils of the Falklands have such low pH values that only potatoes and oats can be grown as field crops. For this to be remedied drainage operations will have to be undertaken. Since much of the area where stone runs occur is carpeted by quartzite blocks even under the soil cover, drainage schemes will be difficult to devise. Thus soil development on these areas will be greatly hindered. It is estimated that this condition will apply to 25% of the total area of East and West Falkland.

The stone runs of the Falklands are, therefore, largely an accident both of past climate, and the structure and lithology of the Upper Quartzite Series. Hill creep, freeze and thaw, frost heaving and solifluction all contributed to the formation, but their importance must be kept in true perspective.

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25/11/49
B.M. 31/1/50

Returned by Mr. H-Smith 13/1/50

B.M. ~~31/1/50~~
25/2/50

B.M. for Dr. Fuchs
+ Mr. Adie
5/3/50

My brief observations of Feb 1948 led me to think that the "stone rivers" are merely surface representation of drainage occurring below blocks of quartzite weathered out *in situ*. This drainage removes all small material from between the big blocks and does not permit peat formation on the surface. Alteration of drainage channels occurring beneath the surface can today be seen to be undermining and removing the surface peat and widening the 'stone rivers'.

I am therefore basically in agreement Joyce's conclusion though he could have elaborated his deductions somewhat.

V. Fuchs. 5 March 1950.

Agree with Mr. Joyce's conclusions.

R. J. Adie 8 March 1950.

P.A.

H.E. The Governor of the Falkland Islands, with the author's compliments and respects.

Stone Runns of the Falkland Islands

J.R.F. Joyce
17:V:50

BY

J. R. F. JOYCE

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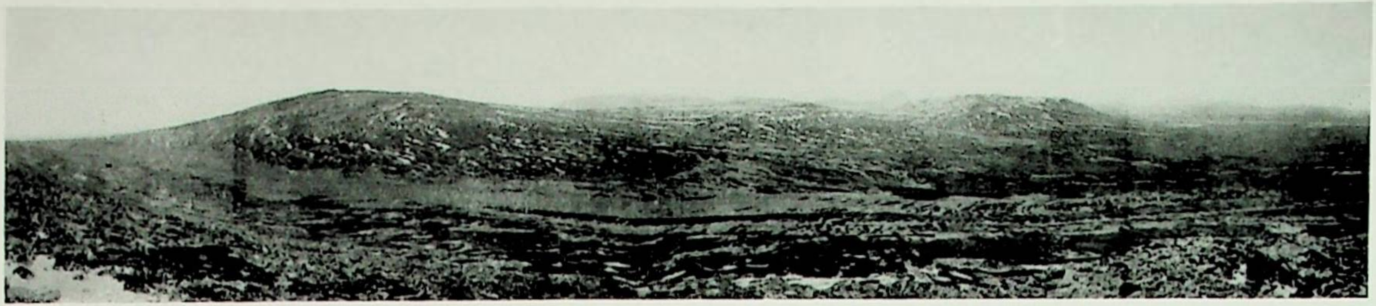

FIG. 1.—DARWIN'S "STONE RIVER" AS FIGURED BY ANDERSSON (1906).

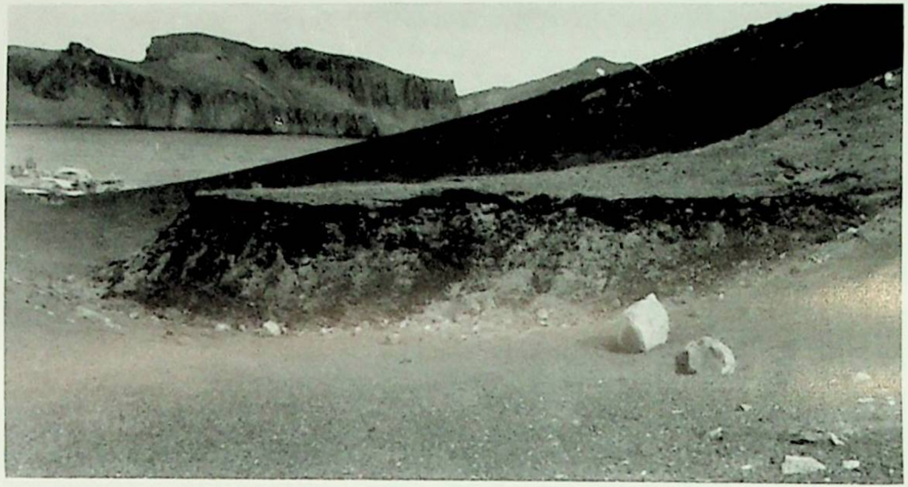

FIG. 2.—A RECENT MUD FLOW, DECEPTION ISLAND, SOUTH SHETLANDS.

Stone Runs of the Falkland Islands

By J. R. F. Joyce

(PLATE VII)

Abstract

The suggestions made by previous writers are summarized, and Andersson's Solifluction Theory is discussed in detail. Reasons are given why the author believes that solifluction alone could not provide the explanation. Stone runs are shown to be largely an accident of past climate and the structure and lithology of the Upper Quartzite Series rocks. A note on the economic aspect of stone runs is added.

SINCE the earliest published descriptions, the stone runs of the Falkland Islands have been a source of interest and speculation to geologists and physical geographers. When Gunnar Andersson (1906) proposed the solifluction theory of their origin, the matter seemed closed, for this theory has been generally accepted as satisfactorily accounting for their formation. Unfortunately the Falkland Islands are remote and little visited by scientists who have the time and opportunity to study the phenomena. This paper is based on studies of the stone runs of East Falkland. There was no opportunity to visit West Falkland, but Falkland Islanders who could speak from personal knowledge were questioned as to the localities where the runs occurred. Their reports were collated and recorded on the Admiralty Chart, which is the only map available. The time now seems opportune to bring to notice some serious objections to Andersson's theory and provide a further explanation.

No observer attempted either a scientific description or an explanation until Darwin (1846) published his excellent account of the stone " river " at the head of Berkeley Sound (Plate VII, fig. 1). This was to him so awe-inspiring that he invoked the agency of a catastrophic earthquake as the explanation. It was left to Wyville Thomson (1877) to suggest something nearer the truth when he said that many factors took part in their formation. He selected alternate drying and saturation and vegetation decay as causing hill creep, which he took to be the transporting agent. From Darwin's and Thomson's descriptions James Geikie (1894) suggested that the stone runs were comparable to the rubble drift of southern England, and that they are essentially a product of tundraic conditions where " freeze and thaw " attains a maximum effect. Andersson (1907) carefully studied the suggestions made by these authorities and incorporated such of their ideas as seemed to him sound in his paper. He made a most painstaking scientific study and map of the stone " river " described by Darwin.

Darwin (1846) selected for his description the stone run most like a river ; had Andersson selected a less river-like example in another area he might have had cause to modify his ideas considerably.

Andersson proposed that the stone " rivers " are caused by the flow of supersaturated soils which bore with them the stone blocks. This process he says is still operative in the Falklands, and he shows a photograph of a present-day mud flow at Port Stevens, on West Falkland. Baker (1922), unable to find himself in agreement with Andersson, postulated local ice caps with quartzite ridges as nunataks. From these nunataks, he says, frost action detached large blocks which " slithered down the icy slopes ".

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His theory of the formation of the stone runs can be criticized in the following argument. Not all stone runs lie progressively downhill ; there are some notable examples which lie across the tops of low dome-like hills. This feature is mostly noticeable where the dips of the underlying rocks are low. On the boundary of the Devono-Carboniferous Series and the Lafonian Series no stone run flows over the Lafonian. Since Wickham Heights, which overlook the Lafonian, are the highest range on the Islands, it is here that one would expect the greatest development of the stone runs. This is not the case. The material of the stone runs is always quartzite, obviously parted on the jointing and bedding planes, and blocks can attain in many instances considerable size. Some measured on the Moody Valley stone run are estimated to contain more than 40 tons in a single block. Such blocks would surely have sunk, under gravity, to the bottom of any viscous mass more rapidly than they could have been transported laterally. Further, they are so numerous that they would have soon jammed immovably on the gentle slopes, where friction and the

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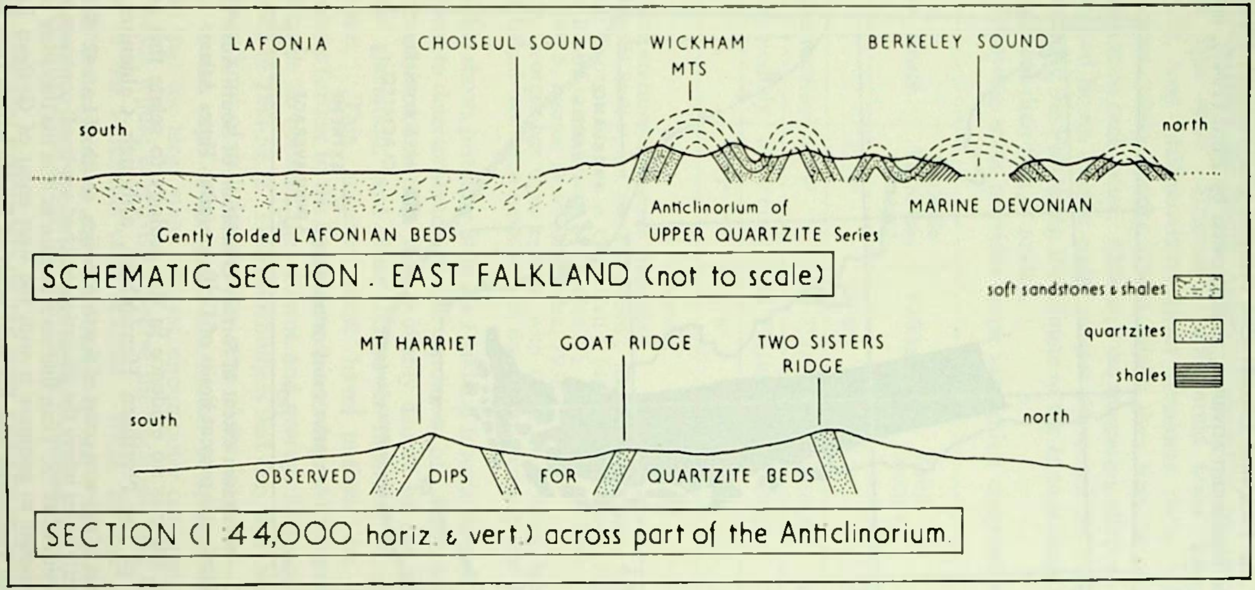
The distribution of these rocks is shown on maps in the works quoted. Observations on East Falkland show that stone runs are confined within the boundaries of the Upper Quartzite Series. The plotted occurrences from West Falkland confirm this. Stone runs, for reasons which will be shown, are not everywhere found within these boundaries.

The tectonic pattern of the Falklands is not known in great detail, and adequate topographical maps are lacking. The general strike is east and west in the northern part of the islands, but Falkland Sound is a line of discordant strike. Whether or not there is much faulting and overthrusting cannot be discussed here, but the distinct rucking between the tectonic lines at the north end of Falkland Sound can scarcely have occurred without some enormous accommodation in the rocks. Over the main outcrop of the Quartzite Series on East Falkland the structure is that of a sharply folded anticlinorium, with a distinct suggestion of some strike faulting. The individual folds in the anticlinorium are of small amplitude, especially where the quartzite bands are thin. In the field, rocks can be seen dipping to both flanks of the anticlinorial axis. In the centre the dips are high, becoming much lower towards the north than they are on the south side of the axis. The sections in Text-fig. 1 demonstrate this.

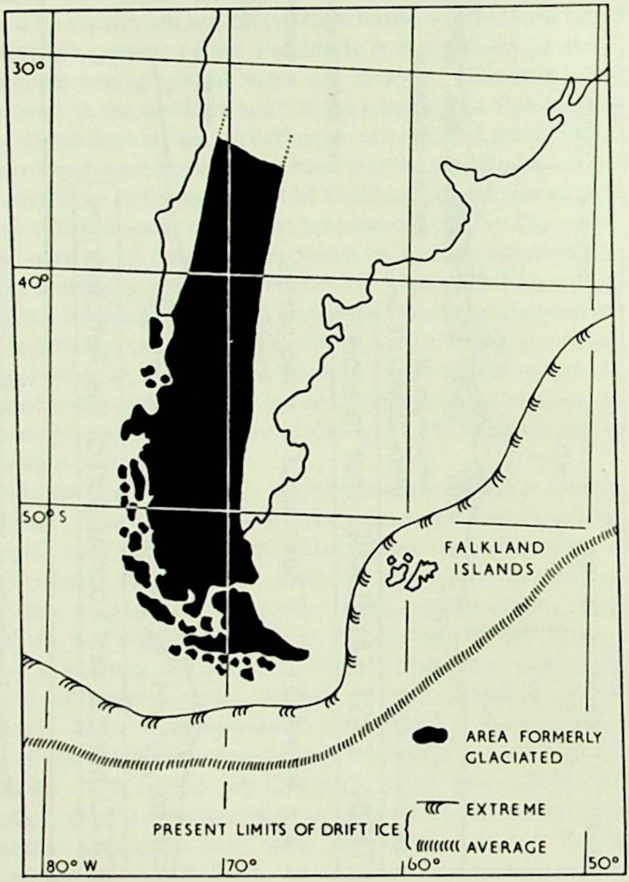
Within the Quartzite Series the two main rock types are quartzites and shales. Some of the quartzites appear in hand specimen to be fairly well recrystallized, while others have the appearance of being siliceous sandstones. Between these two types there are all gradations. Where the quartzites are sharply folded, saddle-shaped vughs have opened on the bedding planes at the crowns of the folds. Quartz crystals have been deposited in these vughs. In vughs exposed in dissected anticlines quartz crystals can be found lying loose and separated. Here is an easy road for attack by the pressure splitting action of ice formed in already made partings in the solid quartzites. The shales, both within the Quartzite Series and within the Marine Devonian, show a cleavage lying at variable angles to the laminations. The angles appear to vary with the intensity of the folding. The cleavage causes the shales to break very rapidly into trapezohedral fragments, often less than an inch and rarely more than a few inches in length. The fragments are often highly iron-stained and, as the shale is fairly rich in pyrites, it weathers easily.

In the Falklands, as remarked by Andersson (1906), evidence of glaciation is entirely lacking. There are no ice-moulded forms, striations, roches moutonées, moraines, or tills. A few erratics, however, are found, but these are confined to the shores, and may be explained as having been transported by ice rafts. There is no evidence that the Antarctic ice ever advanced to South America, and the glaciation there was only an advance of the Andean ice cap ; and, indeed, it seems



TEXT-FIG. 1.—Geological sections across East Falkland.

clear that the Falkland Islands also escaped glaciation in Pleistocene times. The maximum advance, as suggested by Flint (1947), is shown in Text-fig. 2.[1]



TEXT-FIG. 2—Maximum extent of former Glaciation of South America (after Flint) and present limits of Drift Ice (after Times Atlas).

Further, there is no evidence in the geology to relate this advance with that of the Northern Hemisphere, although Caldenius (1932)

[1] The form of the west coast of South America, south of Lat. 42° S. (i.e. the most northerly point where the glaciation reached sea-level) contrasts strongly with that north of 42° S. I can find no reference to it in the literature but I am strongly tempted to compare it with the west coast of Graham Land, as described by Holtedahl, and the west coast of South Island, New Zealand, south of Lat. 44° S.

attempts to place the South American glaciation on the De Geer Swedish time scale. Simpson (1930) would make them contemporaneous, and Milankovitch (1930) considers them slightly dis-synchronous, while Brooks (1949) thinks they may be without any time-relation to each other. Although the tempering effect of the South Atlantic and South Pacific water masses prevented the Antarctic ice from reaching the Falklands, the climate of the Islands must have been more rigorous than that of to-day.

The following table provides some interesting comparisons.

Temp. Means	Latitude 50° S. (sea average)	Falklands	South Georgia	Bear Island
Yearly	41·9°	42·8°	37·8°	29°
Maximum monthly	46·9°	49·3° (Jan.)	43·5° (Feb.)	41° (Aug.)
Minimum monthly	37·4° (July)	36·7° (July)	27·9° (July)	17° (Mar.)
Range. . .	9·5°	12·6°	15·6°	24°

Notes.

(1) All temperatures in degrees fahrenheit.
(2) Falklands Station is Cape Pembroke ; (data from Brooks, 1920).
(3) South Georgia Station is Grytviken ; (data from Brooks, 1920).
(4) Bear Island quoted from M.O. 4466 (7), vol. 11, pt. 7, 1941.
(5) Lat. 50° S. quoted from Meinardus, 1938.
(6) South Georgia has three months with the average temp. below 32° F.
(7) Bear Island has seven months with the average temp. below 32° F.

The table shows just how little the Falkland Islands climate of to-day would have to deteriorate to produce conditions of " freeze and thaw ". The amount is not outside that probably caused by the advance of Antarctic glaciation, and Bear Island is included to provide a comparison. This advance must have pushed the Antarctic Convergence further to the north than it is to-day. At the present time the Falklands lie between the extreme and average limits of drift ice, as is shown in Text-fig. 2. The probability is that they then lay between the average limit of drift ice and the edge of the ice pack. How near they lay to the edge of the pack is a matter of speculation.[1] It is probable that the large water masses, circumpolar currents, and prevailing winds would effectively disperse the pack ice long before the latitudes of the Falklands were reached. What, however, seems a reasonable assumption is that the waters of the Falklands in those times were often quite polar because of the increased quantity of drift

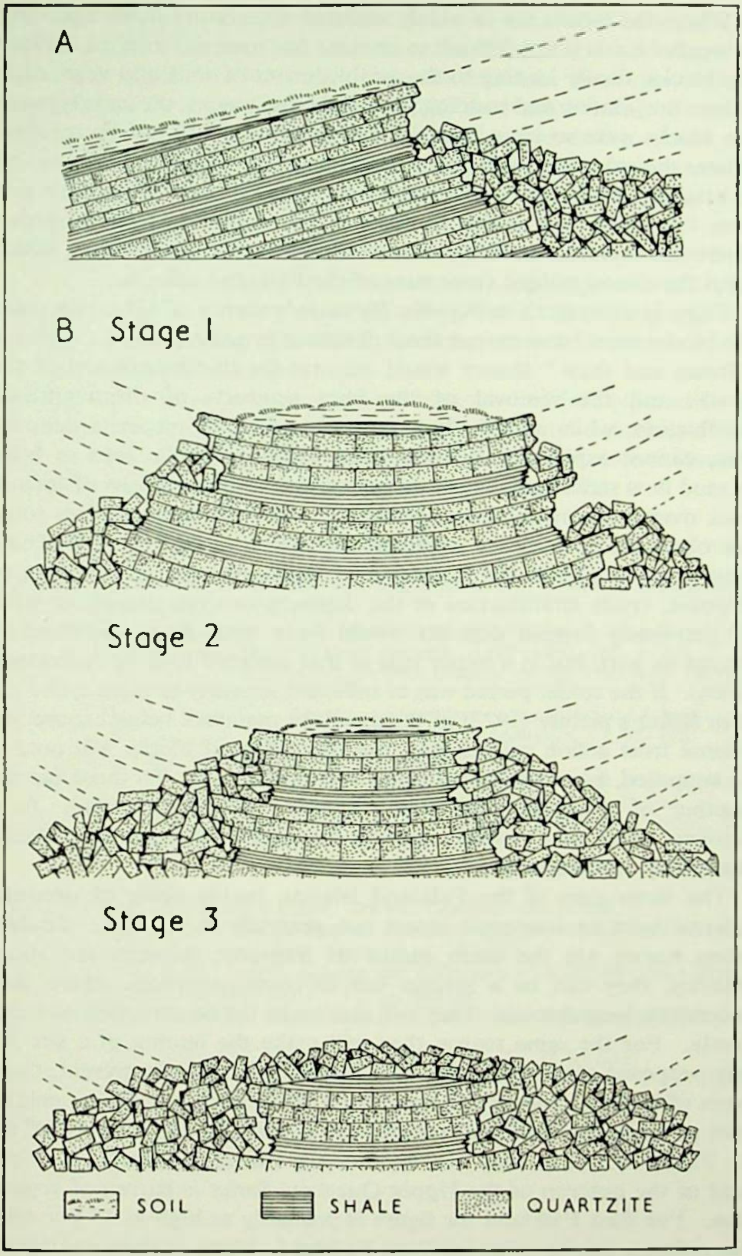
[1] In the hope that information on this score might be deduced from ice rafted erratics, I searched the literature for records. None was found, and surely here is a useful line of research.

ice. At the same time, the polar front must have been farther north, bringing the Falkland Islands more often into the region of cold air behind the front than it does to-day. When more is known about the peats, the soils, the raised beach deposits, and the West Point Island Forest Bed this past climate may be less of a matter of speculation.

The preceding argument provides evidence for the main causes of the formation of the stone runs. To picture the method of formation is not difficult when we remember firstly, the rock series composed of quartzites, resistant, jointed, and bedded, contrasting with the shales, easily weathered and already in small trapezohedral fragments ; secondly, the small sharp composite folds of the anticlinorium ; and thirdly, a possibly long period of tundraic or near-tundraic climate.

If the climate was tundraic, " freeze and thaw " would be operating at its maximum, and as a consequence the quartzites and shales would show differential disintegration. The quartzites, not being readily subject to weathering and being almost homogeneous, would only be affected along the major jointing and bedding planes, which were already opened by the folding for the attack by frost. Because of the frequency of the individual folds, at least near the axis of the anticlinorium, the attack would take place at many points at the same time. The shale already in small fragments would, in addition to frost action, show some weathering, and the fine material produced by this would be removed rapidly by " freeze and thaw " action. The proportions of quartzite to shale are not known, because of the poor exposures due to masking by peat, but it is believed that the shales are subordinate. Where shales underlie the quartzite, there would be a progressive undercutting and the frost-parted blocks would in the course of time be detached from the scarps. The blocks would remain almost in the position where they fell, and thus would carpet the area over which the scarps retreated. The size of the blocks would be almost entirely controlled by the disposition of the jointing and bedding planes, since frost shattering would have little effect on such a homogeneous material as quartzite, except where it could penetrate into fractures and partings.

On the dip slopes there would be no detachment of the quartzite, as is shown in Text-fig. 3A and, where the dips are small and folding gentle, there would similarly be no breaking up of the strata. This would account for the areas within the Upper Quartzite boundaries, which are free from stone runs, and also for the absence of stone runs on the southern flank of Wickham Heights which is a dip slope. Several dispositions of the strata could account for the occurrence of stone runs which lie across the tops of gentle slopes. In Text-fig. 3B the stages for a gentle syncline are shown. The relation of stone runs to minor tectonic features is also illustrated.



TEXT-FIG. 3.—Diagrams illustrating formation of Stone Runs.

Where the blocks are in widely assorted sizes or are more uniformly of smaller size it is not difficult to imagine fine material trapped between the blocks, finally leading to the establishment of soils and vegetation. Where the jointing and bedding provided large blocks, the gaps between the blocks were so large that the fine material could not be trapped. Where the stone runs were of greater thickness, vegetation was unable to establish itself deep in the stone runs owing to lack of light, so that even this agent was unable to assist in the trapping of fine material. There has therefore never been any vegetation over these areas, which form the almost unique stone runs of the Falkland Islands.

There is some truth in Wyville Thomson's theory of hill creep, since the blocks must have moved short distances in settling down. Geikie's " freeze and thaw " theory would account for the detachment of the blocks and the removal of the finer products of disintegration. Solifluction, while admittedly a powerful agent of subaerial denudation, cannot explain those stone runs which cross the tops of hills. A mud flow sufficiently large and powerful to move millions of tons of rock over 4 kilometres down grades of a few per cent requires some corroborative evidence by solifluction in action to-day. Had it played even a major part in the formation of the stone runs, overlapping of deposits, crude stratification of the deposits, or even ploughing back of previously formed deposits would have been seen. Solifluction played its part, but in a minor rôle to that assigned to it by Andersson (1906). If the colder period was of sufficient intensity to form cyclic ice, then Baker's picture (1922) of the quartzite nunataks being exposed to intense frost action will be true, but the detached blocks will not, as he supposed, have " slithered down the icy slopes ". To those factors another of powerful local action should be added, namely frost heaving, which may possibly account for some of the up-ended blocks figured by Andersson.

The stone runs of the Falkland Islands, beside being of scientific interest have an economic aspect not generally recognized. To-day, when horses are the main means of transport between the sheep stations, they can be a serious bar to communications where they necessitate long detours. They will also make the construction of roads costly. For the same reason they will make the finding of a site for any proposed aerodrome near Port Stanley difficult. At present, those parts of the stone runs which are devoid of vegetation sterilize a greater part of the upper quartzite outcrop than is realized. On sheet 1B of the 1 : 25,000 G.S.G.S. Map No. 4456 of the Falkland Islands, 17·8 per cent of the outcrop of the Upper Quartzite Series is barren of vegetation. For East Falkland the figure is probably as high as 15 per cent. No estimate can be given for West Falkland. None of these considerations is, however, serious when compared with the following effect.

The soils of the Falklands have such low *p*H values that only potatoes and oats can be grown as field crops, and for this to be remedied drainage operations would have to be undertaken. Since much of the area where stone runs occur is carpeted by quartzite blocks even under the soil cover, drainage schemes will be difficult to devise. Thus, soil development on these areas will be greatly hindered. It is estimated that this condition will apply to 25 per cent of the total area of East and West Falkland.

The stone runs of the Falklands are, therefore, largely an accident, both of past climate and the structure and lithology of the Upper Quartzite Series. Hill creep, freeze and thaw, frost heaving, and solifluction all contributed to the formation, but their importance must be kept in true perspective.

The writer wishes to express his indebtedness to Mr. Cameron Ovey, of the British Museum (Natural History), for a critical reading of the manuscript and many valuable suggestions, and to Professor J. Gunnar Andersson for permission to reproduce Fig. 1, Plate VII.

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