Observations of some periglacial features and their palaeoenvironmental implications on sub-Antarctic islands Marion and Kerguelen

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Some quantitative data on patterned ground for the sub-Antarctic islands Kerguelen and Marion are presented. Some features are recognised as fossil and of being a product of cooler than present post-glacial conditions. The present-day sorting is smaller in scale than that produced immediate upon deglaciation. The periglacial features thus record the environmental change since the disappearance of the ice cover.

Sekere kwantitatiewe gegewens oor gepatroonde grond vir die sub-Antarktiese eilande Kerguelen en Marion word aangebied. Sekere kenmerke word erken as fossiel en 'n produk van koeler as teenwoordige na-glasiale toestande. Die huidige sortering is kleiner volgens skaal as die wat direk na deglasiasie geproduseer is. Die periglasiale kenmerke gee dus 'n weergawe van die verandering in omgewing sedert die verdwyning van die ysbedekking.

Introduction

Marion Island (lat. 46°54′S, long. 37°45′E) and Kerguelen Island (lat. 49°21′S, long. 70°12′E) are situated just to the north of the Antarctic Polar Front, within the belt of mid-latitude westerlies (Fig. 1). Both islands are volcanic in origin and have been extensively glaciated in the recent past (Hall 1979b in press, Nougier 1972). Kerguelen (6 000 km^2) has a present-day ice cover of *c* 750 km^2 (Mercer 1967), whilst smaller (290 km^2) Marion Island only maintains a remnant region (<3 km^2) of permanent snow and ice above the 90 km contour. An extensive assemblage of periglacial features is present on both islands (Aubert de la Rüe 1959, Bellair 1969, Hall 1979a, 1981, 1983, Markov 1971, Nougier 1964, Troll 1960) but very little quantitative data pertaining to either the landforms or their formative processes are available. The aim here is to present some new data, on both features and proces-

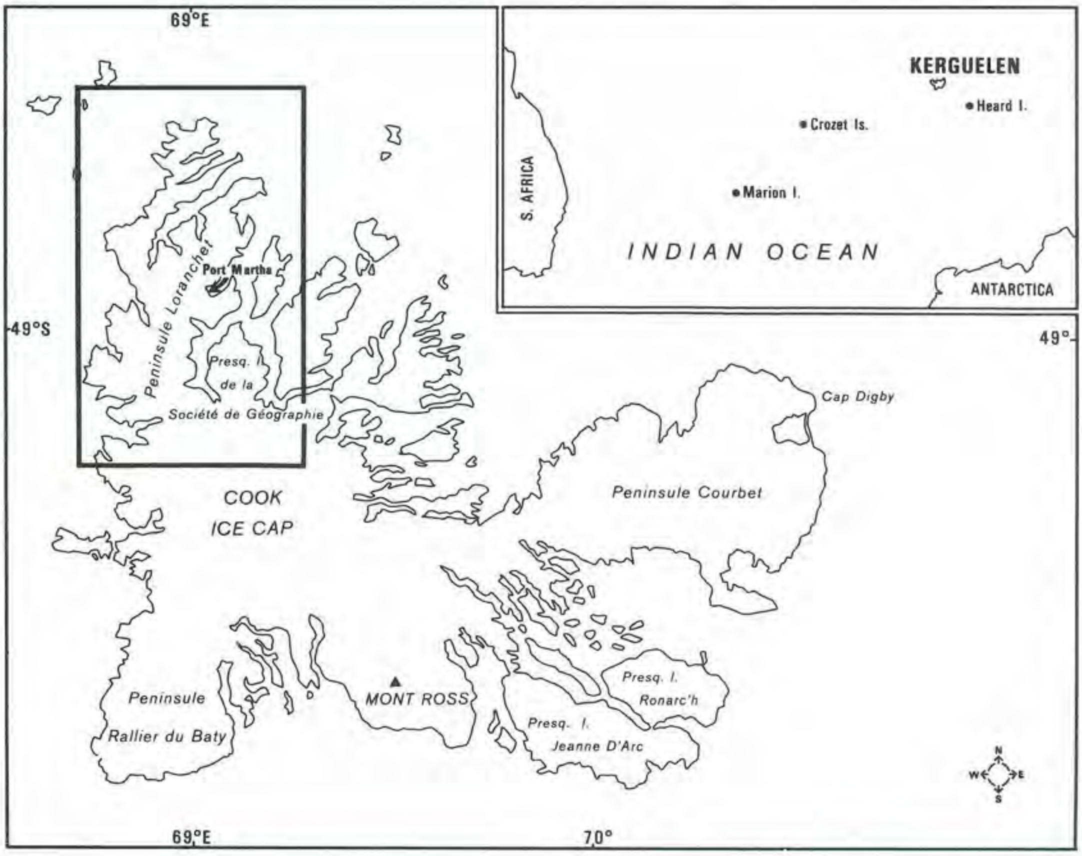

Fig. 1. Map showing the location of Marion and Kerguelen islands together with the study area on Kerguelen.

ses, for periglacial phenomena on both Kerguelen and Marion islands and to use this information to consider environmental changes.

Climatic setting

Both islands experience a typical sub-Antarctic climate of strong winds, extensive cloud cover, frequent precipitation, low radiation inputs and low but equable temperatures with the possibility of frosts any time during the year. Data from Kerguelen indicate precipitation on (approximately) 324 days yr^{-1} with 60 per cent of all observations showing six oktas or more cloud (Aubert de la Rue 1959). During one year Aubert de la Rue (1959) monitored 120 frosts in the air and 200 at ground level, whilst Troll (1944, 1960) recorded freeze-thaw cycles at the ground surface on 238 days yr^{-1} and 236 days yr^{-1}, but with a maximum penetration of 0,05 m.

Marion Island experiences a similar climate with frequent (60 % of occurrences) northwest winds at a mean velocity of 32 km hr^{-1} with, on average, 25 days in each month receiving some form of precipitation (total = 2 576 mm, Schulze 1971). Radiation receipts are decreased by the high incidence of cloud ($\bar{x}$ = 6 oktas), with the amount of sunshine received being cut to 33 per cent of that possible in summer and 20 to 25 per cent in winter (Schulze 1971). Interpretation of meteorological data (Hall 1979b) suggests 48 days yr^{-1} with temperatures of −2 °C or lower at sea level ($\bar{x}$ = freeze amplitude −3,4 °C) and 111 days yr^{-1} at 500 m a.s.l., with a mean freeze amplitude of −4,1 °C (Hall 1979b, Table 1).

Periglacial features

On Kerguelen observations are restricted to Peninsula Loranchet (Fig. 1) for which area details relating to sorted stripes

Table 1
Summary of clast sizes and shapes for two sorted nets at Port Matha.

		$\bar{x}$ a-axis (mm)	s	$\bar{x}$ flatness	s	(1) $\bar{x}$ $\overline{OP}$ Index	s	% oblate	% prolate
NET	1								
	Fine centre:	24	8	307	134	−1,41	5,93	60	30(2)
	Coarse border:	81	17	1300	659	−10,68	29,47	60	40
NET	2								
	Fine centre:	30	7	310	131	−0,04	9,03	40	50(2)
	Coarse border:	97	30	1788	490	−49,39	37,49	90	10

(1) Oblate – prolate index of Dobkins & Folk (1970).

(2) Residue (10%) constitutes clasts with $\overline{OP}$ indices of 0,00.

Fig. 2. An area of sorted nets on the trachytic plug at Port Matha, Kerguelen.

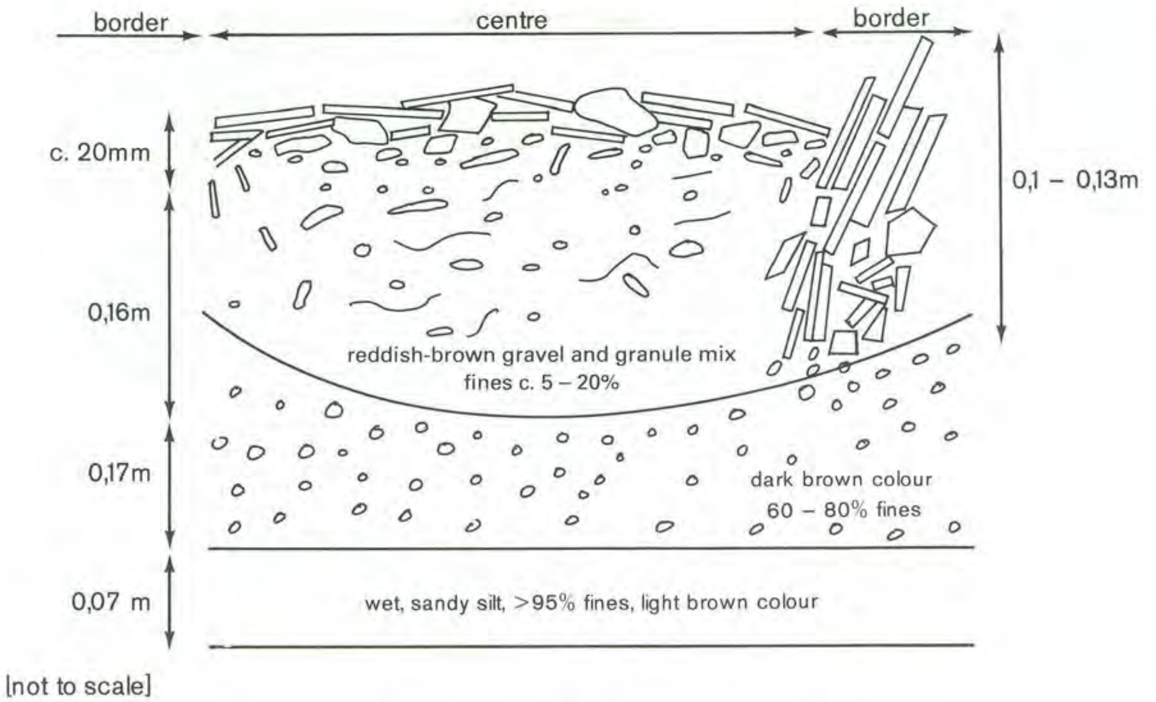

Fig. 3. A section through the sorted nets at Port Matha.

have already been presented (Hall 1983). In addition to sorted stripes a number of observations pertaining to sorted nets were also obtained. Sorted nets, "Patterned ground features occurring in groups whose mesh (interior surfaces) is neither dominantly circular nor polygonal" (Brown & Kupsch 1974), have an extensive distribution on Kerguelen. However, to date they have been described only in qualitative terms (Aubert de la Rue 1959, Bellair 1969, Markov 1971, Nougier 1964, Troll 1960). Quantitative data on sorted nets (Fig. 2) were obtained from an altitude of *c* 60 m on the undulating surface of a trachytic plug at Port Matha (Fig. 1). Weathering, probably some form of freeze-thaw action, breaks the trachyte into angular, platy clasts, the sorting of which generates the nets.

Measurement of the longest axis of net fine centres (n = 25) indicated a variation of between 0,64 m and 0,21 m, with a mean length of 0,35 m (s = 0,12). Coarse border widths varied between 0,09 m and 0,67 m at their widest sections ($\bar{x}$ = 0,27 m). In the coarse borders the clasts reside with their a/b planes normal to the fine centres, whilst in the centres themselves the a/b planes are vertical. Measurement of clast shape and size for the centres and borders indicates a distinct compositional dichotomy (Table 1). The clasts comprising the borders are both larger and flatter than those in the centres. In addition, the border clasts are less well sorted, with respect to size and shape, than are those in the centres.

A section through the sorted nets (Fig. 3) shows that the clasts, in the fine centre, residing with their a/b planes vertical, are in a band only some 20 mm in thickness. Beneath them there is a *c* 0,16 m mix showing vertical sorting. At the borders the platy clasts are aligned normal to the centre to a depth of 0,10 m to 0,13 m, but the number of clasts exhibiting this orientation decreases with depth except at the margin with the centre where it is maintained. Below *c* 0,13 m the border transists into a gravel/fines mix. A distinct transition occurs within the net at about 0,16 m depth, where colour changes to a dark brown and there is a marked increase in the percentage of fines. A further change takes place after another 0,17 m, at which depth a light brown, wet and coarse material deficient zone is encountered. The fine centre of the net tends to show a slight doming and has pockets of sandy silt, some of which break through the surface stone cover.

In the Port Matha area of sorted nets it was observed that some small *Azorella* cushions had been penetrated by flat trachytic plates that had been forced up through them (Fig. 4). The *Azorella* was less than 0,2 m in thickness and showed internal damage due to the upward movement of the clasts. Growth of *Azorella* about the clasts is discounted on the basis of the internal damage and the tenuous position of clasts no longer in contact with debris beneath the vegetation.

What is also noticeable in this area, in terms of their omission rather than inclusion, is that gelifluction features appear to be very scarce. Stone-banked lobes and vegetation-banked mass movement forms are notably lacking compared to Marion Island. *Azorella* is less common in this area but nevertheless major mass movement forms in association with sorting were conspicuous by their absence.

The distribution of recognised periglacial features on Marion Island is shown in Fig. 5. Of these landforms, sorted stripes and stone-banked lobes (sorted lobes) have already been described in detail elsewhere (Hall 1979a, 1981). However, sorted polygons, circles and nets (Washburn 1979) were also observed. Form variety in these sorted features is a result of packing and slope: circles forming polygons due to density of packing and circles/polygons forming nets in areas of gentle slopes (*c* 2-6°). The largest of the observed nets had a fine centre 0,66 m along its greatest axis with a coarser border 0,05 to 0,15 m in width. These sorted features were observed from altitudes as low as 200 m a.s.l. right through to *c* 1 200 m. Circles and nets were also seen developed in a fines-rich till only 0,15 m deep at *c* 300 m on Piew Crags.

In many areas, on both volcanic and glacial debris, "steps" or "terraces" of material banked by *Azorella* risers are found. The bare, sorted tread may be from 1,5 to 10 m in width, with a lateral extent of 3 to 20 m behind a 0,2 to 0,7 m high riser. The vegetation does not appear to be in distress and in only a few instances was material from the tread seen to be moving over

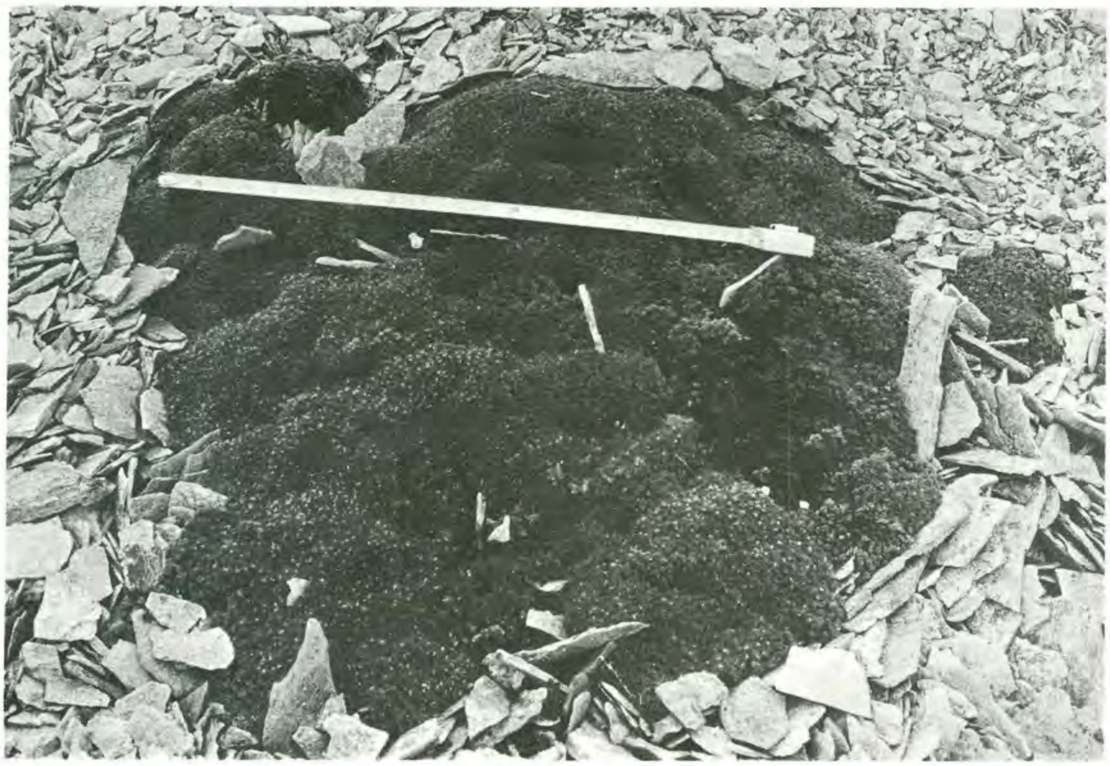

Fig. 4. An example of clasts forced up through an *Azorella* cushion at Port Matha.

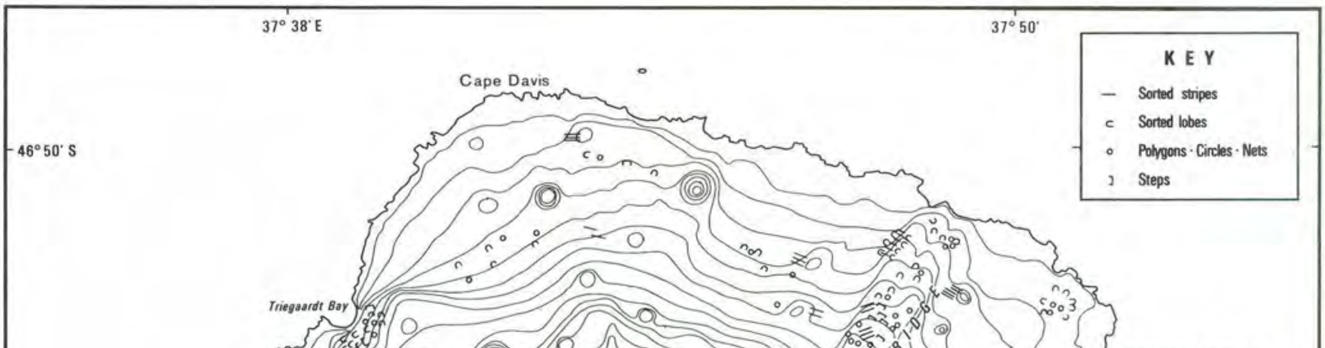

Fig. 5. The distribution of periglacial features observed on Marion Island.

or through the vegetation riser. These steps were found in areas of a 5° to 20° general slope which, subjectively, often appeared to be wet. On the steeper, more debris-strewn slopes beneath rock outcrops, were found mass movement forms characterised by stone-banked lobate snouts. Some of these stone-banked lobes, those with a sorted, fines-rich tread, have already been described (Hall 1981), but there were others which exhibited a surficial covering of rock debris. These were usually larger forms than those which had the bare soil treads and can be in the region of 15 to 20 m long, 4 to 5 m wide and 1 to 1,5 m high. Surface clasts tend to be platy and angular and to lack any preferred orientation. Beneath the one or two clast-thick surficial layer there is a sorted zone with the coarser clasts at the top, fining downwards.

Field observations throughout a year showed the presence of pipkrake at all altitudes above 50 m a.s.l., whilst lenticular freezing of the ground, to a depth of 0,15 m, was observed at heights in excess of 250 m. The pipkrake attained lengths of 50 mm and occasionally exhibited evidence of more than one growth phase. The effects of aspect and shadow were pronounced in prolonging freeze duration and increasing depth of freeze. Basalt outcrops were often seen to show severe fracturing and block disintegration, with large spreads of angular blocky or platy debris mantling their lower slopes. However, thermoclastis under present, or, more likely, past severer conditions, cannot be assumed as the sole cause for strain release or crack propagation forces other than freeze-thaw may be responsible (Whalley *et al.* 1982, McGreevy & Whalley 1982), particularly in igneous rocks such as basalt.

Discussion

The periglacial features recorded here for Marion and Kerguelen islands offer nothing new or exciting in themselves other than their recognition, in new geographical localities, and some quantitative measurements. However, when viewed in terms of their formative processes they are indicators of broad environmental changes from the end of the last glacial through to the present. Seen as a whole, the periglacial assemblage represents a continuum of landforms varying in scale as an adjustment to climatic amelioration.

The glacial-postglacial boundary is suggested to be about 12 000 BP in this sub-Antarctic region (Schalke & Van Zinderen Bakker 1971). However, on Marion Island ^{14}C dates obtained from the base of thick peat sections (Lindeboom 1979, Scott pers. comm) suggest that peat growth at the coast (i.e. the area first ice-free) was only initiated *c* 7 000 BP. This then suggests that there was a time-lapse of several thousand years between deglaciation and development of a vegetation cover. During this phase the ground would have been exposed to temperature variations without the damping influence of a vegetation mat: ideal conditions for periglacial activity. In addition, as the ice-caps waned, even extremely rapidly as in the case of Marion (Hall 1982), the lower regions would have been subject to cold katabatic winds. At the same time, there would have been a greater incidence of cold southerly winds than at present for the retreat of the Antarctic pack-ice would not have been at the same rate as island ice-cap diminution. Thus, the lowland on the islands would have been continuing to experience colder-than-present conditions although the greater ice cover found on Kerguelen (Hall, in prep.) would have retreated at a much slower rate than on Marion Island, so that there would not have been synchroneity of coastal region exposure on the two islands.

Reconstruction of temperatures for Marion Island (Hall 1979b) suggests that mean annual values were only 2 – 4 °C cooler than present, although the greater incidence of cold southerly winds was an additional influence inducing greater cooling. Thus, both thermoclastis of rock outcrops and depth of sorting in the ground were more extensive that at present. The suggested drop in temperature would have given numerous freeze-thaw cycles with a freeze amplitude of −3 °C or lower, a value which McGreevy and Whalley (1982) indicate to be the threshold for effective mechanical weathering by ice action. The greater depth of sorting in the ground would explain the presence of large, possibly fossil, sorted stripes observed on Kerguelen (Hall 1983) and the large, rubble-covered, stone-banked lobes found on Marion Island, for in both cases the depth of sorting is far greater than is presently possible. The enhanced freeze-thaw activity would have produced the large, angular plates and blocks found on the lobes of Marion Island, and may have caused the breakdown of the trachyte in which the sorted nets on Kerguelen then developed as the fines produced allowed ice segregation and hence sorting.

It is probable that the *Azorella*-banked steps found on Marion Island were initiated during the immediate post-glacial cooler phase. Similar steps, or terraces, are described on Macquarie Island (Taylor 1955, Löffler pers. comm.). The "leeward terraces" of Taylor (1955, Fig. 1) appear from the descriptions to be identical to those found on Marion Island and are noted as having (p. 134) their ". . . position and dimensions . . . constant for a long period of time". In fact Löffler (pers. comm.), from studies in 1979 and 1980, considers them "relict solifluction landforms developed during a more severe frost climate". Taylor (1955) suggested that the terraces developed due to banking of material behind established *Azorella* and that solifluction played very little, if any, part. Löffler, however, considers the slopes on which the terraces developed to be insufficient for scree movement and so it is necessary to invoke periglacial solifluction (gelifluction) to explain the downslope mass movement. This then implies that the *Azorella* grew in the sheltered position offered by the terrace riser and thus was a result of, rather than a cause of, the terrace. On Marion the steps/terraces occur on general slopes even gentler than are found on Macquarie, plus the vegetation shows no sign of stress or destruction, and so a similar causal sequence to that suggested by Löffler is envisaged. In fact Löffler (pers. comm.) suggests that the time of development was ". . . at the end of the last glacial immediately upon the disappearance of the ice . . ." and that during this phase temperatures were at least 4 °C lower than at present, a figure very similar to that derived for Marion Island. The apparent lack of these forms on Kerguelen is puzzling and no satisfactory explanation has yet been forthcoming. Certainly, terraces developed close to the glacier margins would have been destroyed during the Neoglacial advance, but this still leaves vast areas where features could have survived and, considering Kerguelen has a severer climate than Marion or Macquarie, may have still been active.

The present-day processes of pipkrake action, wetting and drying, segregation ice to depths of *c* 0,05 m, and the influence of strong, frequent winds (Hall 1979a, 1983) account for the small sorted features and the slow downslope creep of material. Whether the present climate is sufficiently severe at the lower altitudes for thermoclastis is uncertain, due to lack of micrometeorological data. However, the frequent occurrence of pipkrake which require an initiation temperature of at least −2 °C (Outcalt 1971) suggests that some rock destruction due to sub-zero temperature cycling may be operative. Thus the small-scale sorted circles and nets are a product of the present climate, and probably some rock breakdown continues to take place, thereby providing coarse and fine material for sorting.

Conclusions

The periglacial assemblage on Marion and Kerguelen comprises two major groups: one set, now probably fossil, resulting from conditions severer than at present, the other currently active under the present-day climate. The post-glacial climatic amelioration together with the concomitant growth of a vegetation cover has resulted in a diminution in the effectiveness of freeze-thaw cycles, both on rock faces and in the ground. As a result a number of features produced under the severer conditions are no longer active and they have been superseded by smaller-scale processes giving a different landform assemblage. The presence of the fossil features indicates that the climate has ameliorated sufficiently since the end of the last glacial so that a threshold, with respect to development and maintenance of a number of landforms, has been reached. Although presently active patterned ground on Marion and Kerguelen are of roughly the same sizes, it would appear that the marginally cooler climate of Kerguelen produces deeper sorting than is found on Marion. In addition, the greater frequency of temperature cycling about the 0 °C isotherm produces highly active patterned ground on Kerguelen plus the greater potential for thermoclastis.

These generalised observations point the way to a need for detailed research on sub-Antarctic periglacial features on these islands, and a call is therefore made for a multi-disciplinary investigation of the periglacial landforms and history of the South African island, Marion. For such a study, micro-meteorological monitoring on rock faces and about presently active patterned ground, plus detailed measurement of landform size variation with altitude and aspect could prove fruitful. Dating of buried organic horizons (^{14}C method) would help both in establishing the age of fossil features and in estimating rates of gelifluction. All observations to date have been highly simplistic and qualitative when viewed against the depth of periglacial research in the Arctic and alpine regions (c.f. Washburn 1979) and thus a major gap in the pedological, botanical, morphological, climatic and environmental history of these islands is present.

Acknowledgements

Financial and logistical support for the work on Marion Island was provided by the Department of Transport on the advice of the South African Scientific Committee for Antarctic Research. Financial and logistical support for the research on Kerguelen was provided by T.A.A.F., whilst travel costs for this expedition were provided by the University of Natal to whom thanks are due. Professor J. Nougier kindly organised the Kerguelen expedition and obtained permission for my participation. The French Air Force helicopter crews are thanked for their patience in getting us to key sites, often in poor conditions. Map and diagrams were redrawn by Bruno Martin.

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