DAILY MONITORING OF A ROCK TABLET AT A MARITIME ANTARCTIC SITE: MOISTURE AND WEATHERING RESULTS

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ABSTRACT. The mass of a tablet of indigenous rock was monitored daily for one year in order to study changes in moisture content and timing of weathering losses. The broad climatic conditions to which the tablet was subjected were noted. It was found that, within the maritime Antarctic, freezing temperatures occur when rocks have high moisture contents. Although rock tablets may be considered 'unnatural', they can provide valuable information on daily variability of moisture status which is essential for the planning and interpretation of realistic weathering simulations.

INTRODUCTION

Rock tablets, despite being somewhat 'unnatural', have been used in a variety of geomorphological studies such as the investigation of erosion rates (e.g. Trudgill, 1975; Crowther, 1983), the study of rock weathering in soils (e.g. Day and others, 1980), for the measurement of rock temperatures by means of internally located thermistors (Whalley and others, 1984) and for the monitoring of rock moisture variation on a wave-cut platform (Trenhaile and Mercan, 1984). Weathering studies, particularly of building materials, have frequently utilized exposure trials of tablets of rock or man-made products (see McGreevy and Whalley, 1984, for a review). The classic study of Ritchie and Davison (1968) utilized bricks of various materials to monitor moisture changes as a function of aspect and, with thermocouples fitted within them, to record the incidence of freezing and thawing. Other cold-environment studies of this type include those of McMahon and Amberg (1947) and Ritchie (1972) who studied the effects of frost action on bricks, and Cook (1952) who investigated the effects of freeze–thaw upon concrete in a marine environment. In a similar manner, Trenhaile and Mercan (1984) considered the moisture content of rock on a wave-cut platform as a control upon frost damage, whilst Chatterji and Christensen (1979) evalulated the frost damage to limestone nodules as a function of different moisture contents. In the Antarctic, Miotke (1982) has obtained temperatures around a small piece of rock on the floor of one of the dry valleys (Taylor Valley). However, probably due to logistical constraints, no long-term study of daily changes to tablets of indigenous rock has been undertaken in the Antarctic.

As part of the British Antarctic Survey Fellfield Ecology Research Programme a study is being undertaken of the mechanical weathering processes operative in a maritime Antarctic environment (Hall, 1986*a*, *b*, *c*, 1987*a*, *b*; Hall and others, 1986), and involves concurrent field and laboratory investigations. As an extension of this programme, a project was initiated to investigate, albeit in a very simple manner, the daily changes in the mass of a tablet of local rock and to record the general climatic conditions to which it was subjected. It was hoped that such data, for the period of a whole year, would provide preliminary information on daily moisture variability and on weathering rates.

METHODOLOGY

Rock samples collected on Signy Island (60° 43′ S, 45° 38′ W; see Hall, 1986*a*, for details of study area) were cut into small tablets and, following the procedure of

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Cooke (1979), the porosity, microporosity, water absorption capacity and saturation coefficient of each ascertained. The tablets were then returned to the field in the austral summer 1983–4 with the aim of retrieving some of their number each year and re-testing them to see, as a measure of weathering, if any of the properties had changed. In January 1985, one block was moved to outside the scientific station to allow its daily mass to be recorded. Unfortunately it was not possible to use micrometeorological logging equipment to detail the specific conditions to which the tablet was subject. Thus, only broad, generalized statements concerning temperature, snow or rain, wind, dryness, sun, or whether the tablet was covered (by snow or ice) were possible. Nevertheless, this information is comparable with that which is usually available for the bulk of field sites and is certainly equal to what is used for the general description of large areas.

Only one tablet was used, but the results are considered to be typical for quartz-micashist, which comprises the bulk of the island. The tablet was kept in an open environment with its schistosity parallel to the ground surface, replicating the attitude of most exposures.

Results and Discussion

Despite the simplicity of approach, the data offer, for the first time from this environment, daily information for a single piece of rock over the span of a whole year. Details of the properties of the tablet left in the field at experiment start (1983–4) are given in Table I, whilst graphs of daily change of mass together with the broad

Table I. Properties of the rock tablet

Property	*Value*
a-axis (cm)	11.02
b-axis (cm)	3.30
c-axis (cm)	2.38
Cailleux flatness index	300.80
Oblate–prolate index	18.20
Maximum projection sphericity	0.54
Porosity (%)	1.46
Water absorption capacity (%)	0.31
Saturation coefficient	0.21
Microporosity (%)	16.82
Water absorbed in 24 hrs (g)	0.23
Water absorbed under vacuum (g)	1.07

climatic conditions to which the tablet was subjected are given in Fig. 1. Occurrences of 'major' (> 0.20 g) changes in mass, either on a daily or a cumulative (i.e. several successive days) basis, are presented in Table II. The value of 0.2 g was chosen upon the recognition that a rise of this magnitude constitutes a significant (> 87%) saturation of the rock in terms of potential for damage if that rock is then subject to freezing (White, 1976). A decrease in mass by this amount (0.2 g) would imply a relatively 'dry' state such that it unlikely to be damaged by freezing conditions.

The significance of the 0.2-g increments of moisture in abetting frost action may seem contentious in the light of the recent comments by Walder and Hallet (1986). However, it is argued that whilst the model of Walder and Hallet (1985) is a significant step forward in our understanding of rock damage due to freezing water,

Table II. Details of major weight gain or loss experienced by the rock tablet

Gain/loss	*Weight (g)*	*Dates(s)*
Maximum weight gain in 24 h	0.35	9 April 1985
Gain of ⩾ 0.20 g in 24 h	0.22	7 February 1985
Gain of ⩾ 0.20 g in 24 h	0.21	10 March 1985
Gain of ⩾ 0.20 g in 24 h	0.21	12 March 1985
Gain of ⩾ 0.20 g in 24 h	0.21	25 March 1985
Cumulative gains of > 0.20 g	0.20	25–28 February 1986
Maximum wt loss in 24 h	0.23	24 February 1985
Loss of ⩾ 0.20 g in 24 h	0.22	8 February 1985
Loss of ⩾ 0.20 g in 24 h	0.20	11 March 1985
Cumulative loss of > 0.20 g	0.22	6–8 April 1985
Cumulative loss of > 0.20 g	0.22	27–30 April 1985
Cumulative loss of > 0.20 g	0.20	16–19 October 1985
Cumulative loss of > 0.20 g	0.29	2–5 January 1986
Cumulative loss of > 0.20 g	0.25*	14–21 January 1986
Cumulative loss of > 0.20 g	0.20*	3–4 July 1985

* Weight loss includes material weathered free.

it is by no means universally applicable. Within this experimental programme, ultrasonic evidence has been obtained at freezing (Hall, 1987*b*) which clearly indicates a singular, massive water-to-ice phase change of > 80% of the water available to freeze within the rock. Under these conditions, it is those rocks with the greater moisture content which, despite some extrusion of ice, will suffer the greatest damage due to the 9% volume change which occurs as the water turns to ice. In addition, there is the possibility that rocks subjected to omnidirectional freezing may be damaged by hydrofracture (Walder and Hallet, 1985; Hall, 1986*c*) and, once again, it would be those rocks with the higher moisture contents that should sustain greatest damage. This is not to negate the detrimental effects of other weathering processes (e.g. wetting and drying) that are also operative, but rather to point out the significance of moisture content with respect to freeze–thaw. However, at the same time, the data presented here must be viewed in the context that it is simply a daily change of mass that is recorded. No account of any changes of pore volume, due to frost damage, during this period are quantified although this is something which could be expected to increase with time (Walder and Hallet, 1986).

Consideration of Fig. 1 indicates a number of broad trends with respect to changes in tablet mass. First, it can be seen that there are relatively frequent, large, short-term changes from spring through to autumn, whilst the winter period (late May to early September) has much more subdued daily variations. Secondly, it is evident that there is a gradual overall diminishing of tablet mass through the year, after an initial rise in April. Thirdly, it is apparent that the loss of tablet mass is progressive, rather than a stepwise diminution resulting from incidents of large particle loss.

That the greatest daily changes in mass took place during the spring-to-autumn period is not particularly surprising as it is during this time that some precipitation falls as rain and positive temperatures predominate (Fig. 1). Much of the winter period (*c*. 80%) has below zero temperatures, with values as low as −27 °C being recorded (21 June), and limited sunshine with very limited potential for local melting. There is thus very little unfrozen water available to penetrate the rock. During much of the winter period the tablet was covered by snow or ice, thereby further precluding water availability. During the spring-to-autumn phase there is a significant occurrence of rain (15% of the days) at times when the rock is not covered by snow or ice and

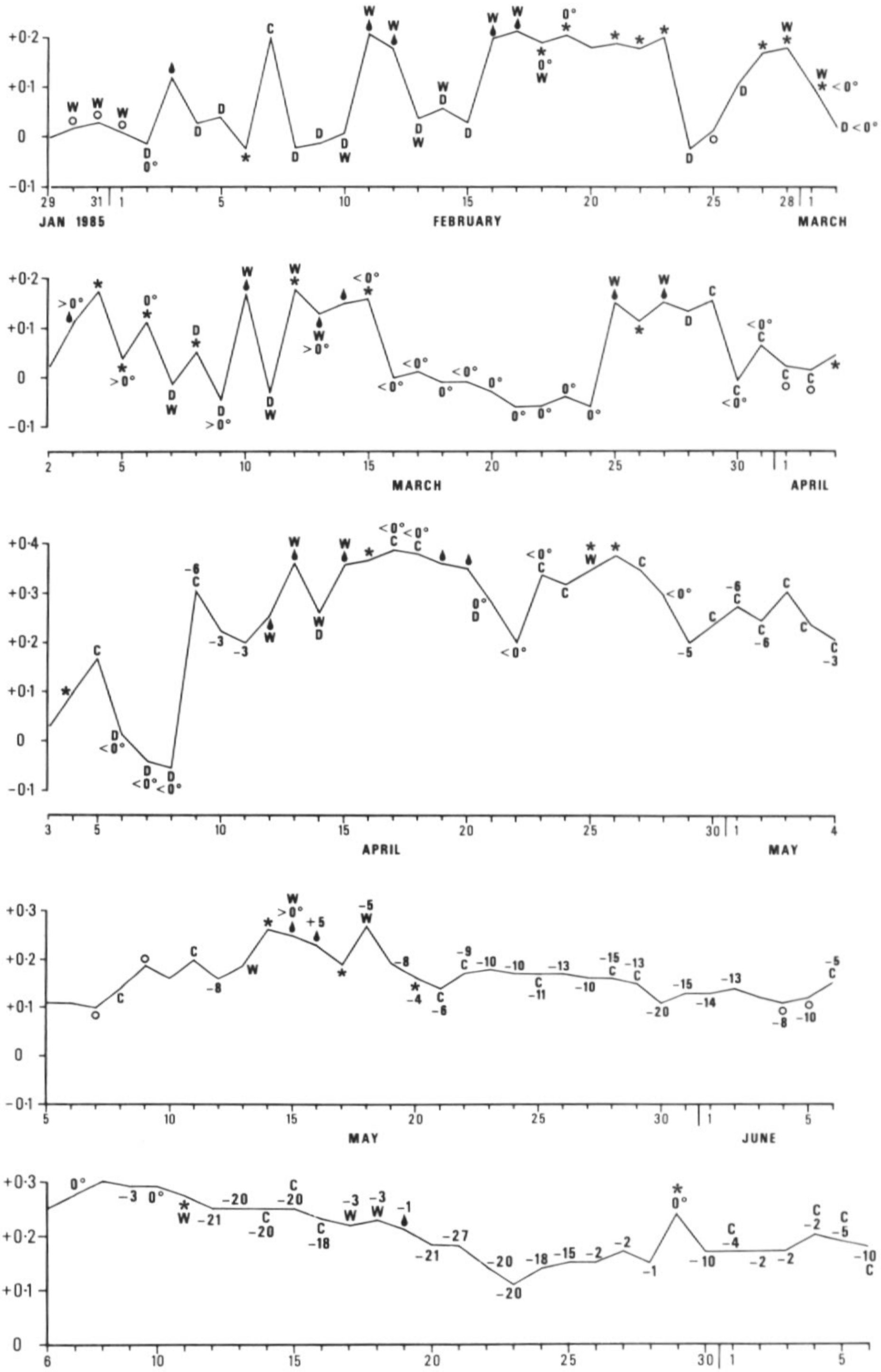
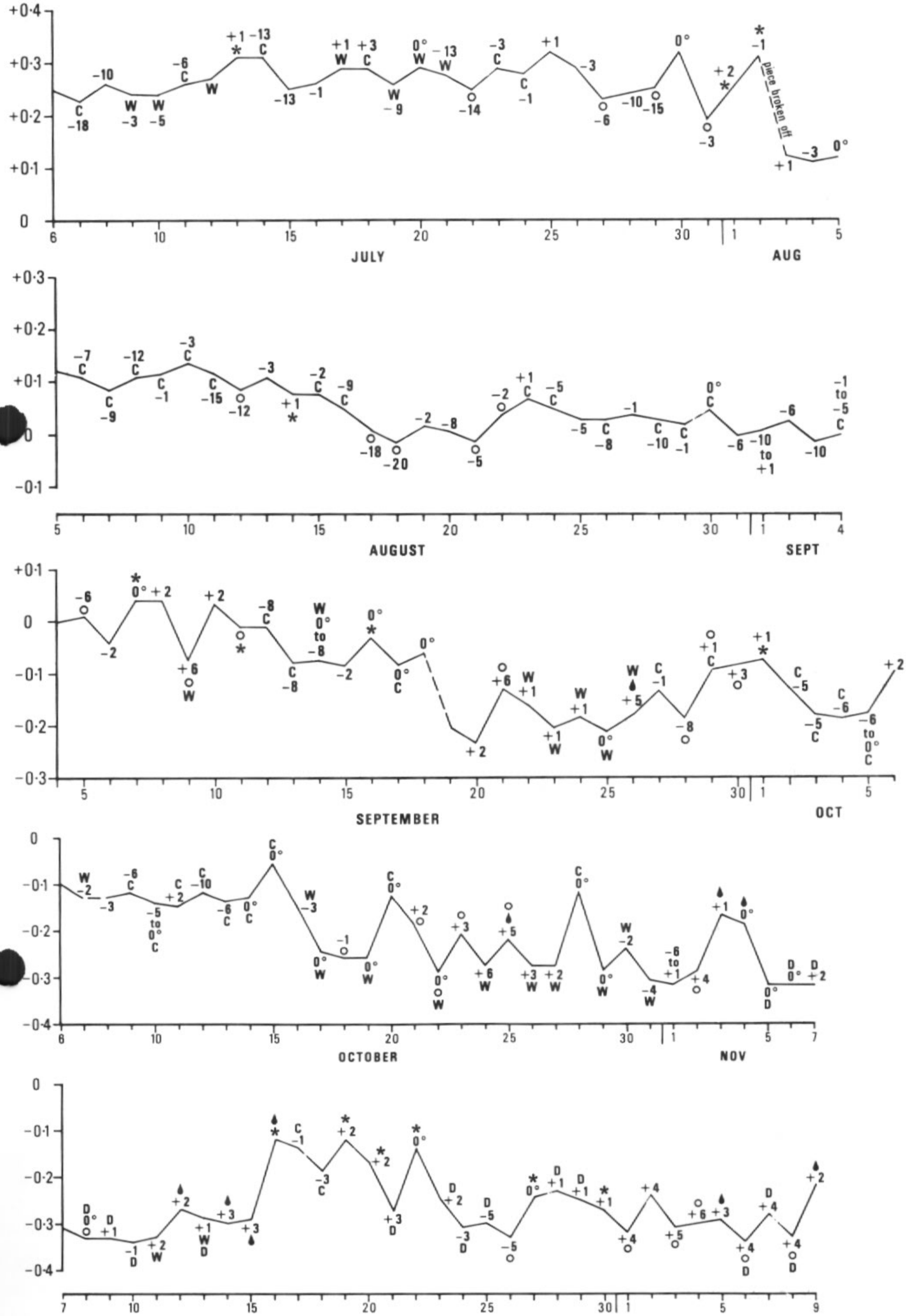


Fig. 1. (Caption on p. 22.)


+0·4
+0·3
+0·2
+0·1
0
JULY
AUG
piece broken off
+0·3
+0·2
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-0·1
AUGUST
SEPT
+0·1
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SEPTEMBER
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Fig. 1. (cont.)

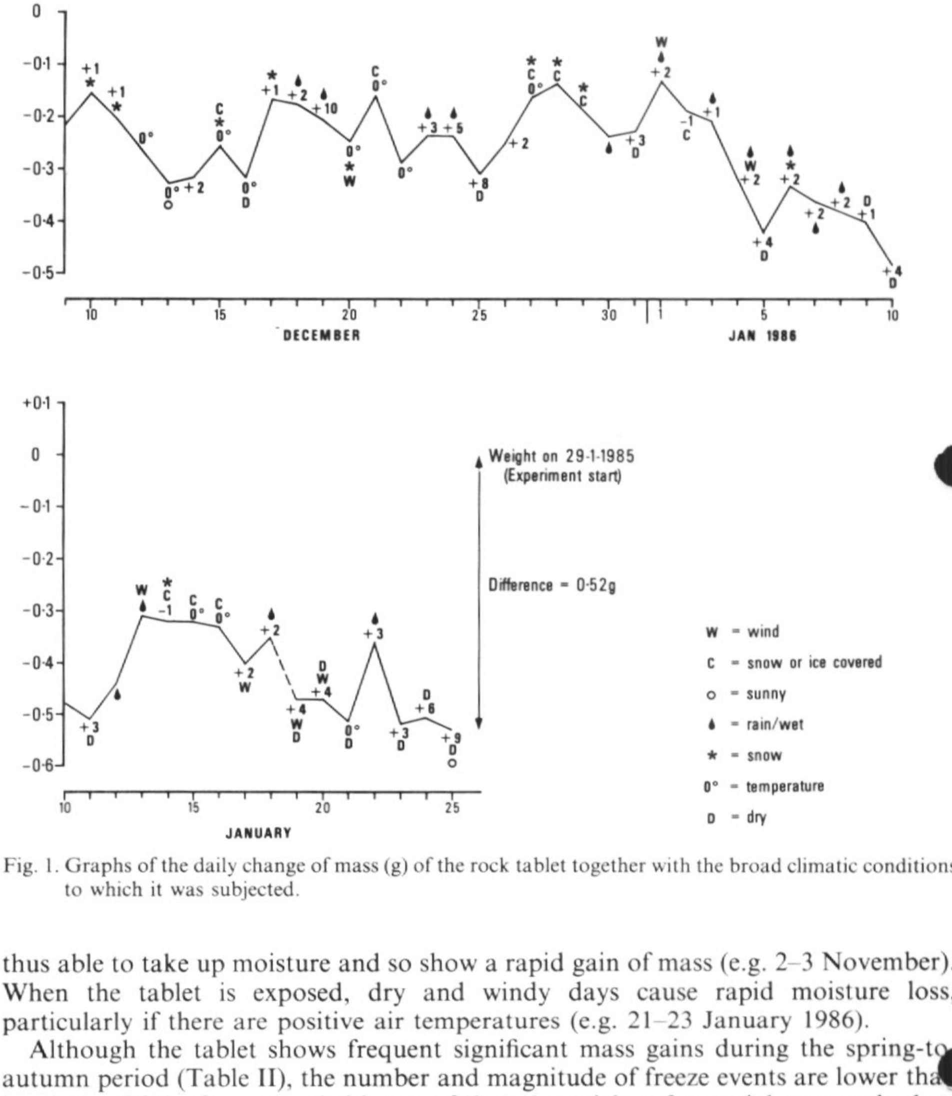

Fig. 1. Graphs of the daily change of mass (g) of the rock tablet together with the broad climatic conditions to which it was subjected.

thus able to take up moisture and so show a rapid gain of mass (e.g. 2–3 November). When the tablet is exposed, dry and windy days cause rapid moisture loss, particularly if there are positive air temperatures (e.g. 21–23 January 1986).

Although the tablet shows frequent significant mass gains during the spring-to-autumn period (Table II), the number and magnitude of freeze events are lower than in winter. Of the four recorded losses of 'large' particles of material, two took place in winter (2 August and 18 September) and two in the following summer (7 October and 18 January). Of the two summer events, one (7 October) took place during continued negative temperatures, but was of a very small effect (0.02 g), whilst the other occurred during a thaw phase.

The progressive diminishing of tablet mass is interesting insofar as, if there were an increase in internal voids due to frost action, as suggested by Walder and Hallet (1986), then some gain in mass might have been anticipated due to the greater water-holding capacity of the sample. This increase of mass can only be attained though if the following three constraints can be met: (1) internal frost damage *does* occur, (2) water is made available to the rock, and (3) the rock is able to take up the water. However, in practical terms, monitoring of mass gain due to the above effects may be masked by loss of rock material resulting from weathering, and so some increase of water-holding capacity may have taken place. Consideration of Fig. 1 suggests that the only time there was an unequivocal mass gain was on 9 April. From 8 to 9 April there was a gain of 0.35 g, an increase of 0.12 g above what the rock was initially found to absorb under non-vacuum conditions in 24 hrs (Table I). After that sudden jump, there was a gradual decrease in mass, with various gains and losses dependent upon climatic conditions, until the first recognized loss of rock material on 2 August (0.19 g). A downward trend in mass then continued, through 4 September, when the original start mass was attained once more, to the end of the study period.

Patently frost and/or salt action are not the only possible weathering mechanisms to which the tablet was subject. Such processes as thermal fatigue are possible during the summer period when relatively high daytime temperatures alternate with cooler night-time conditions, particularly when shading may take place to cause rapid cooling. Wetting and drying is an inherent part of freeze–thaw insofar as the moisture status of the rock varies. There is some evidence (Hall, in press) to show that this absorption and desorption causes changes in the elasticity of the rock and may, via hysteresis, cause fatigue to the rock. However, neither of these processes are well understood and, apart from some laboratory information on the latter (Hall, in press), no data are available. In addition to these mechanical weathering processes it is recognized that some degree of chemical weathering is possible, particularly during the summer months, and that biotic processes may also occur. Although the time span of only one year is relatively short such that, in an evironment of this kind, mechanical processes might be thought to predominate, ancillary studies of chemical and biotic weathering currently in progress may later throw some light on their relative contributions.

With respect to the process of freeze–thaw, it is very likely that under omnidirectional freezing the water is not able to move to the freezing front as required by Hallet (1983). Conversely, the schistose nature of the rock may, in some instances, facilitate hydrofracture (Powers, 1945; Walder and Hallet, 1985). If crack expansion is insufficient to accommodate the volume increase as water changes to ice then there will be forcible expulsion of water ahead of the freezing front which may cause damage to the rock – hydrofracture. If ice can only grow along the laminate mineral interfaces, then the tensile forces will oppose each other and so crack expansion due to ice growth may not be possible (see Hall, 1986*c*, fig. 3). This situation would be conducive to hydrofracture. At the same time, it may well be that due to the relatively small size of the tablet, freeze penetration may be so rapid that a massive phase change occurs thereby precluding hydrofracture. If this were the case then it is probable that due to a moisture gradient the bulk of the water is in the outer part of the tablet and so ice extrusion may well occur (Davidson and Nye, 1985) thereby limiting the amount of damage to the rock.

McGreevy and Whalley (1985, p. 344), in their highly pertinent discussion on rock moisture content, noted that in the study of Ritchie and Davison (1968) high degrees of sample saturation rarely coincided with freezing conditions. In this respect the maritime Antarctic may differ, for Fig. 1 shows that the mass of the tablet, and hence its moisture content, was relatively high on a number of occasions when freeze–thaw took place. For example, from the end of April through to early August the mass is high and negative temperatures, down to −27 °C, are seen to occur. All in all the tablet appears to have been subjected to 39 freeze–thaw cycles during the course of the year, but it must be kept in mind that it had been in the field one year prior to experiment start and therefore subject to weathering that cannot be evaluated here.

A possible complicating factor is that the frequent oscillations in moisture content that took place during parts of the year (e.g. early March) would appear to be conducive to weathering by wetting and drying. Further, the limited data available on interstitial water solute chemistry (Hall and others, 1986) suggests an $NaCl$ content of between *c.* 0.3 and 0.6 M. This, then, adds the further possibility, as has been suggested by Williams and Robinson (1981), McGreevy (1982) and Fahey (1985), of the interoperation of frost and salt weathering. Thus, although the data from the tablet do provide new information, much more needs to be done before the relative contributions and interactions of the various weathering processes are known.

Conclusions

Overall, this experiment attempted to provide data in answer to the questions and criticisms posed by McGreevy and Whalley (1985) with respect to the moisture status of rocks in the field. Although a very simplistic approach and lacking in climatic detail, the information presented here does, nevertheless, give a record of daily variations in the mass of a tablet of rock resulting from gain and loss of moisture together with material loss due to weathering. As a cut block, open on all sides, the results cannot be construed as relating to cliff-face situations but they do approximate to the loose, fallen blocks found over much of the island. In fact, the tablet probably provides a base-line value insofar as the irregular surface of the naturally occurring blocks probably hold, and lose, more moisture.

The data indicate the possibility, in the maritime Antarctic environment, of rocks having relatively high moisture contents at a time when they may experience freezing. There are seen to be daily changes in moisture content, particularly during the spring-to-autumn period, and this wetting and drying may promote rock fatigue. Salts are present in the rock and weathering due to salt activity may also take place. The interaction of at least these three weathering processes (freeze–thaw, wetting and drying, salt) appear to produce progressive weathering of the tablet. However, it may well be that, due to the 'cut' rather than 'natural' nature of the tablet, the experimental period was not long enough to discern true weathering rates.

It is suggested, based upon the evidence obtained in this pilot study, that long-term field measurement of representative samples could be of great use to the understanding of weathering processes and rates. More particularly, it can help to provide a firm data base from which to construct laboratory simulations. The results presented here relate only to the weathering of *small* blocks in the maritime Antarctic. A complementary study of large blocks, with more detailed monitoring of environmental factors, would prove an ideal extension of this current experiment.

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