Biological Weathering on Nunataks of the Juneau Icefield, Alaska

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Short Communication

A Note on Biological Weathering on Nunataks of the Juneau Icefield, Alaska

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ABSTRACT

Observations on a number of nunataks of the Juneau Icefield indicate that chasmolithic algae play a major role in the breakdown of granitic rock. Expansion and contraction of the algal mucilage, caused by wetting and drying episodes, results in the surface flaking of the rock. Available data suggest that the average mass of material lost per year from 1 m^2 of rock could be as high as 562 g. It is suggested that biological weathering may be a major destructive mechanism of the granitic lithologies.

RÉSUMÉ

Des observations sur plusieurs nunataks du glacier Juneau indiquent que des algues chasmolithiques jouent un rôle capital dans la rupture des roches granitiques. L'expansion et la contraction du mucilage algaire, dues à des périodes de sécheresse et d'humidité entraînet la détachement de plaques superficielles de roche. Les données disponibles suggèrent que la masse de matériau perdue par an sur une surface de 1 m^2 de roche peut atteindre une valeur aussi élevée que 562 g. Il est suggéré que cette altération biologique peut être un mécanisme de désagrégation capital pour des roches granitiques.

KEY WORDS: Biological weathering Algae Nunataks Juneau Icefield

INTRODUCTION

The physical and chemical role of lichens, algae and bacteria in rock breakdown has been recognized for some time and for a variety of environments. Muntz (1890) was the first to suggest that bacteria play a role in rock breakdown, while at about the same time Bachmann (1890, 1892) was investigating the effects of lichens on the weathering of different rock types. In addition to their chemical role (e.g. Branner, 1897), the mechanical effect of these organisms has long been recognized (e.g. Fry,

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1924, 1926). The role of these various biological agencies has been considered as significant in deterioration of building material (Mellor, 1922; Palmer, 1989) as well as for their effects on rock breakdown in various environments, particularly hot deserts and Antarctica (e.g. Friedmann *et al.*, 1967; Friedmann, 1971; Broady, 1981; Kappen *et al.*, 1981; Friedmann and Weed, 1987). Algae have received less attention than either bacteria or lichens but in recent years their effects in desert areas, particularly the Antarctic, have been recognized (Friedmann, 1971; Friedmann and Ocampo, 1976; Broady, 1981; Vincent, 1988). According to Friedmann and Gulun (1974), the so-called 'lithophytic algae' (i.e. rock algae) occur in four broad groups: epilithic (on the exposed rock surface), chasmolithic (in fissures), endolithic (in the internal air spaces of the rock fabric) and hypo- or sublithic (on the undersurface of light transmissive stones found in soil).

Studies to date on the Juneau Icefield have emphasized the role of mechanical weathering processes (Hamelin, 1964; Shenker, 1979; Klipfel, 1981; Linder, 1981) and, to a lesser extent, chemical weathering (e.g. Dixon *et al.*, 1984). However, during the summer of 1989 observations on a number of nunataks of the Juneau Icefield indicated that biological agencies, primarily algae, were a major contributor to rock breakdown.

STUDY AREA

The Juneau Icefield (Figure 1), a relict of the great Cordilleran ice sheet, covers an area of approximately 4000 km^2 along the Alaska–Canada Boundary Coast Range (Marston, 1983). Some 30 glaciers drain the Icefield, which is situated within a maritime environment along the southern and western edges of the Coast Range but which becomes more continental inland towards the east. Specific details regarding the glaciers, climate and mountains of the Icefield can be obtained from Miller (1964). The studies were undertaken at two main sites, designated as C-10 and C-18 (Figure 1). C-10 (Camp 10) is on a nunatak that rises to a height of *c.* 1555 m a.s.l. and approximately 426 m above the surrounding ice. Observations were obtained from the west-facing side of the nunatak. Additional data were obtained from the C-18 (Camp 18) region on nunataks just to the south of the Alaska–Canada border, in the region of the Gilkey Glacier at an altitude of *c.* 1700 m a.s.l. Sampling took place from glacier level to *c.* 100 m above the ice.

METHODOLOGY

Observations regarding extent of rock damage were made on randomly identified 1 m × 1 m or 0.5 m × 0.5 m areas. In these squares the area of either the damaged or undamaged surface was obtained by measuring (to the nearest millimetre) the main axes of the affected parts. In some instances it was only possible to measure the areas involved, while at other times samples of rock material removed were immediately weighted and then later, if possible, dried in an oven at 105 °C for 24 h and weighed again, so that both the mass of rock removed and its moisture content could be calculated. Equally, at some sites the mass of the removed material was obtained but the area it was derived from was not calculated. Samples of the active organisms were collected and returned to the laboratory, where they were cultured for identification. General field observations regarding the distribution of biologically weathered bedrock, its altitude and aspects together with lithological associations were made.

RESULTS

Biological activity was only apparent on granitic rocks in the study areas. No evidence of biological weathering could be found on the dark, gabbroic lithologies, where a distinct relationship of other mechanical weathering processes to aspect was observed, with the south-facing sides of outcrops showing severe granular disintegration, while the north-facing sides were resilient and unaffected. The granitic rocks showed no such effect of aspect but rather had a 'pock-marked' appearance as though hit by a geological hammer (Figure 2). Thin bands of green-coloured algae were also often present and were particularly evident along the edges of the rock after a flake had been removed. It was very noticeable that while these flakes could be removed with ease during and immediately after wet weather, no amount of prising with steel knife blades could dislodge them subsequent to several days of hot weather. The removed flakes (Figure 3), of which large numbers could be found at the base of outcrops, were all in the region of 2–4 mm in thickness but varied greatly in their areal expression (measurements from 4 cm^2 to 600 cm^2 were recorded).

Measurements regarding the biologically affected area, the area of additional material that could easily be removed, the total affected area and the weight of material removed are given in Table 1. In

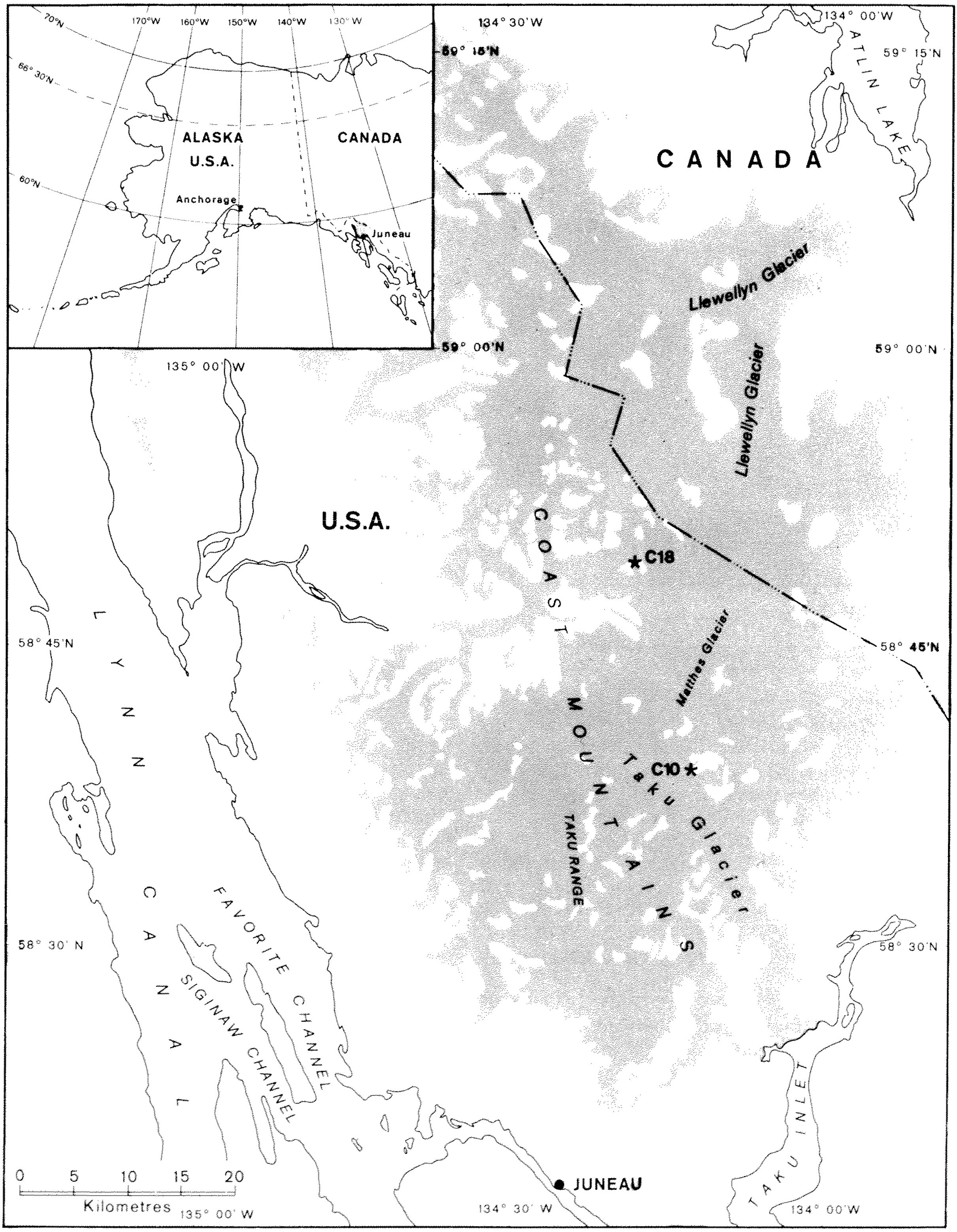

Figure 1 Location map showing the position of the study sites on the Juneau Icefield.

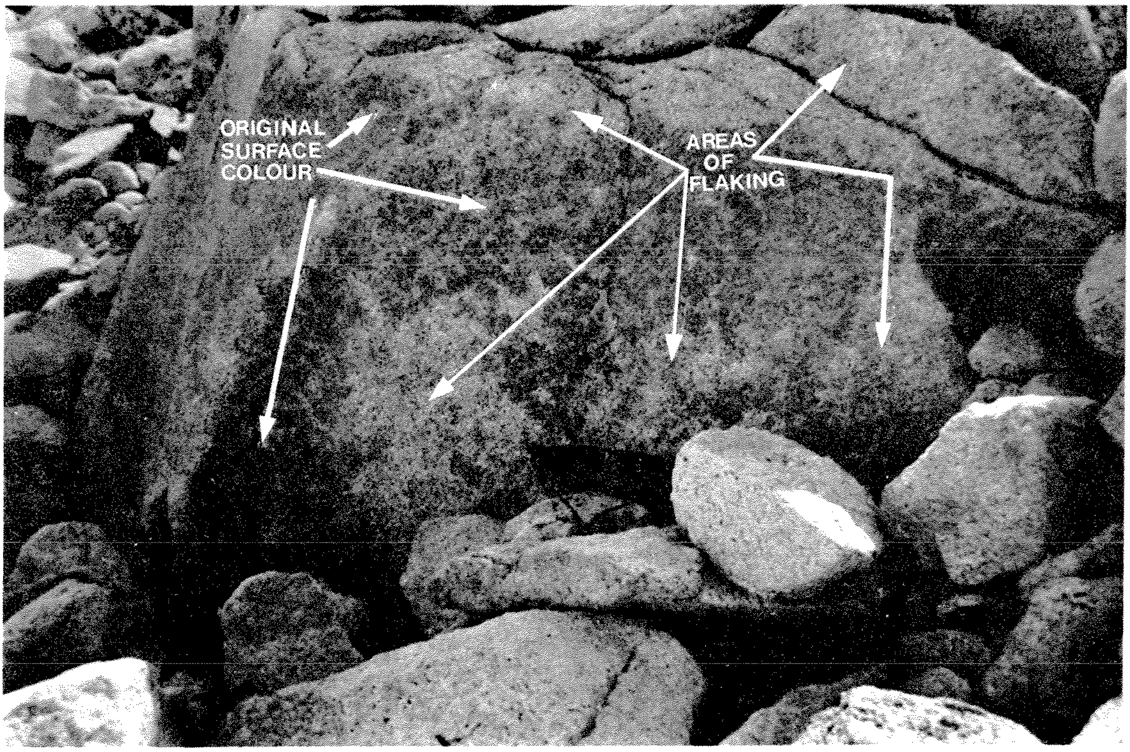

Figure 2 Flaking due to algal mucilage expansion and contraction on one face of a granitic boulder at the C-10 site.

addition, it was found that at several exposures there were inclusions of gabbroic rock within the granitic pluton which were unaffected by biological weathering and thus protruded above the surrounding surface. As the edges of these small (*c.* 5 cm × 5 cm) protrusions were stepped, it appears that they give some indication of the amount of material that has been removed; measurements ranged between 2.5 mm and 15 mm. Finally, it was most noticeable that the areas where active flaking appeared to be operative were relatively lichen-free, while surrounding unaffected lithologies had an extensive cover.

Cultures of the organisms from the rock indicate the presence of two species of chlorococcalean green algae, one filamentous form (single cells in a common mucilage) and a fungus. The chlorococcales are green in their early stage of development but can change to a red colour in later stages or when under stress from high temperatures and/or light intensity. It is thought that the fungal growth lives on the algal photosynthates or on the dead algae.

DISCUSSION

The algae are probably of the chasmolithic type (i.e. living in fissures or cracks within the rock), utilizing microcracks parallel to the rock surface that were created by dilatation. Although Friedman (1971, p. 419) states that alpine lithophytic algae are less well-researched than those of hot and cold deserts, it is considered that the algae live in the rock as a means of avoiding stressful environmental conditions (Vincent, 1988). Certainly the Juneau Icefield provides a range of stressful environments, from very cold in winter to very hot and dry in summer. During the study period rock surface temperatures (Hall, in preparation) attained levels as high as 38 °C and values of 20–25 °C were common on many days. That the chlorococcalean is a green alga but was seen mostly as red-coloured may also reflect stressful conditions for high light intensities and temperatures cause the chlorophyll to degrade, thus causing a change in colour from green to red. In other words, the red colour of the (green) alga indicates a green alga under stress.

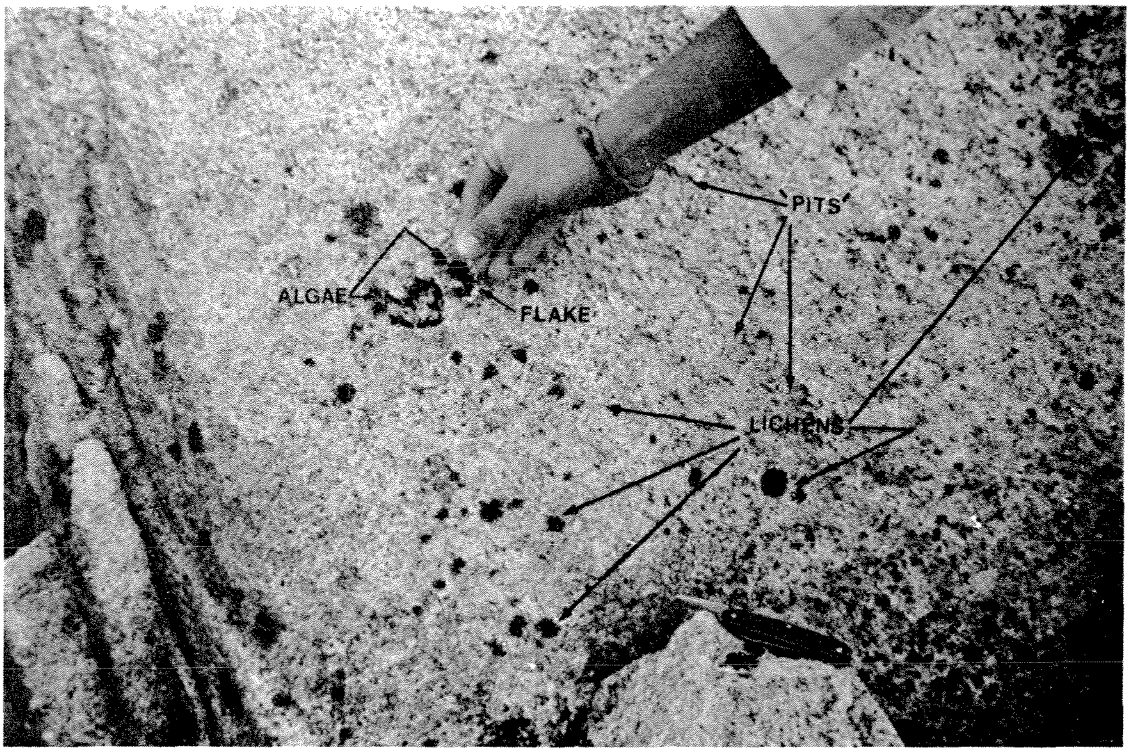

Figure 3 Granitic flake removed by hand with algae attached.

In order to retain their moisture during dry phases algal cells will first lose water from their surrounding polymer sheath or 'mucilage'. The latter is secreted by the algae for the protection of the inner cell and the amount of mucilage is partly controlled by environmental conditions: the more stress the more mucilage produced. This mucilage is hygroscopic, and it expands when water is available and contracts as moisture is lost. Expansion can be substantial (twenty-fold according to Correns, 1898) and during drying it exerts a very strong bonding force with a very high tensile strength.

It is this expansion and contraction that is seen as the damaging force. Friedmann (1971, p. 426) suggested that the 'shrinking and swelling of gelatinous cell sheaths... may physically dislodge rock particles... in a similar way to the activity of freezing and thawing'. The observation that plates of rock, with layers of algae up to 1 mm thick still attached (Figure 3), could be lifted free with the utmost ease during, and for a short time after, rain, while no amount of effort, even with a steel knife blade, could remove flakes after several dry days showed the effectiveness of the wetting and drying of the mucilage. The piles of rock flakes found at the base of outcrops clearly demonstrated the efficacy of this process in causing surface flaking of the rock. The flakes then break down into individual sand grains, probably mainly owing to the process of wetting and drying but also aided by thermal fatigue and frost action. Thus, the nunataks show a scene of rock outcrops in various stages of flaking with accumulations of small flakes at their base and the whole area with a covering of unconsolidated sand grains.

The findings of Broady (1981, his Figures 4 and 5) with respect to rock flaking and the extent of algal growth in 50 cm squares in the Antarctic are very similar indeed to the findings on the nunataks of the Juneau Icefield. Broady (1981, p. 263) found chasmolithic algae a few millimetres below the rock surface '...below thin flakes more or less parallel with the rock surface'. The surface flakes in the Antarctic were between 1 mm and 6.5 mm thick, while in the present study they were found to be 2–5 mm thick. Although Broady does not comment

Table 1 Information regarding the damage caused by algae as measured in the field.

Aspect	Angle (°)	Affected area (cm^2)	Extra material easily removed (cm^2)	Total area affected (%)	Dry weight removed by hand (g)	Moisture content (%)
SW-facing	40	780	?	7.8	?	?
Horizontal	0	8500	250	87.5	?	?
Horizontal	0	2800	74	28.7	?	?
Horizontal	0	1943	333	22.8	?	?
Horizontal	0	1723	100	18.2	?	?
SW-facing	90	3792	6	38.0	?	?
Horizontal	0	6572	986	75.6	580	?
N-facing[1]	90	2000	396	24.0	?	?
Horizontal	0	2014	110	21.0	?	?
Horizontal	0	1620	294	19.0	?	?
Horizontal	0	1438	126	15.6	?	?
E-facing[2]	15	?	398	?	579	2
SE-facing[2]	5	?	1251	?	15576	2
N-facing[3]	3	?	?	?	266	?
W-facing[3]	20	?	?	?	114	?
Horizontal[3,4]	0	?	?	?	709	?
S-facing[3,4]	70	?	?	?	456	?
Horizontal[3,4]	0	?	?	?	490	?
		$\bar{x} = 3016.6$	267.5	32.6	596.3	
		$s = 2401.4$	282.2	25.5	438.5	

[1] Surface exposed from under snow cover by digging.

[2] Samples collected during wet weather but affected area not measured.

[3] Material collected but area not measured.

[4] Surfaces had varying gabbroic rock component.

? = data not available, owing to various reasons (i.e. balance or oven not available).

upon the areas exhibiting recent flaking (i.e. areas from which rock had been recently lost), he does note the widespread occurrence of the living algae, they being found in 75 % of the 61 km squares examined. Thus, the role of algae is significant over a large area and it is argued that on many nunataks of the Juneau Icefield they are equally, if not more so, prevalent and active.

From the available data (Table 1) it is difficult to discern whether any particular aspect of the rock is more prone to biological activity. In Antarctica Broady (1981) found growths restricted mostly to the W through SW to SSW-facing sides of outcrops and boulders, mainly on the downwind side of the exposure. However, the sandblasting associated with the powerful winds and hyperaridity of Antarctica is far in excess of anything taking place on the Juneau Icefield. Present data are insufficient to quantitatively show any effect of aspect, but qualitative observation failed to show any obvious orientational bias. Certainly observations about a number of large blocks (*c.* 2 m × 2 m × 2 m) at C-10 failed to show any apparent difference in flaking between any of the faces.

Detailed climatic data for the rock areas do not exist but available information (Hall, in preparation) suggests that during 34 days of observations there were a minimum of 16 wetting–drying cycles. In addition, on a number of nights when snow, rain, drizzle or fog did not occur, there was a relative humidity of $\geqslant 90\%$. Thus, the potential number of times that the mucilage polymer sheath could expand and contract during the spring to autumn period is relatively large (probably > 50) and so the destructive effect of the algae would be expected to be significant, particularly when the degree of expansion that can occur is considered. This same destructive force has been suggested by Palmer (1989) to be the cause of damage to historical churches in northern Germany. One of the churches was completed in 1893 and is already heavily weathered, with large pieces of brick having fallen away, while the other was completed in the eighteenth century and large chips of rock can easily be removed from this (Palmer, 1989). In the first case it is only for 96 years that the bricks have been exposed and in the latter for less than 300 years. In the case of the nunataks the rock may have been exposed for a much longer period. While no valid data are available, observations showed that *Rhizocarpon* sp. lichens in the same areas as the flaking rock suggest that the rock has been ice- and snow-free for 1000 years or more. Thus, considering the potential efficacy of this process, it is not surprising that the upstanding, unaffected gabbroic nodules indicate at least 1–2 cm of material lost over the whole rock surface.

The mass of material that could be removed from 1 m^2 was substantial (Table 1), such that, although no quantitative data are available, qualitative observation of the extent of algal activity suggests that this process far exceeds any other in causing rock breakdown. Certainly, on the basis of the amount of loose material ($\bar{x} = 562$ g/m^2: Table 1) on rock surfaces and the accumulation of algal-derived flakes at the base of outcrops, the effectiveness of biological weathering seems to be substantially faster than that reported by other workers (see Introduction) for either mechanical or chemical weathering. Although *actual* weathering rates are not known, the indication by the upstanding gabbroic inclusions of the loss of 5–20 mm of material over the *whole* rock surface during the last *c.* 1000 years gives some idea of overall mass lost. However, this is still a conservative estimate in so far as it presumes the top of the inclusion to have equated to the original rock surface and this need not have been the case.

Once the flake is detached, then the exposed alga dies. The flake is then broken down by other weathering processes (probably a combination of freeze–thaw and wetting and drying) to produce the grus that abounds on these nunataks. The exposed rock surface is then subject to all but biological weathering until algae can recolonize, at which point the whole sequence is repeated. Thus, any granitic exposure shows all stages of biological weathering activity.

CONCLUSIONS

Until this present study, weathering of nunataks on the Juneau Icefield has been considered to be primarily mechanical, although the role of chemical processes has also been documented. This present study shows that the granitic rocks, in particular, are subject to very dynamic biological weathering. The expansion and contraction of the mucilage of chasmoendolithic algae that accompanies wetting and drying cycles effects a flaking of the rock surfaces. Although it is highly probable that chemical weathering by the algae also takes place, no data are yet available regarding this. However, the mechanical effects of the algae are such that several hundred grams of rock per square metre may be lost each year. The granitic outcrops examined showed the effects of this biological weathering over their entire surface, with large amounts of debris visible at the foot of vertical exposures. The inclusions of unaffected gabbroic rock stand as much as 10 mm or more above the surrounding surface.

It is probable that the role of algae in causing rock breakdown is far more complex than indicated by this preliminary note. However, algae are certainly a major weathering agency on the nunataks investigated and are likely to be operative on other nunataks in this region. More detailed studies, particularly regarding weathering rates and the role of biologically induced chemical weathering, are needed.

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REFERENCES

Bachmann, E. (1890). The relation between calcicolous lichens and their substratum. *Berichte der deutschen Botanischen Gesellschaft*, **8**, 141–145.

Bachmann, E. (1892). The thallus of calcicolous lichens. *Berichte der deutschen Botanischen Gesellschaft*, **10**, 30–37.

Branner, J. C. (1897). Bacteria and the decomposition of rocks. *American Journal of Science* (4th series), **3**, 438–442.

Broady, P. A. (1981). The ecology of chasmolithic algae at coastal locations of Antarctica. *Phycologia*, **20**, 259–292.

Correns, C. (1889). Über Dickenwachstum durch Intussusszeption bei einigen Algenmembranen. *Flora, Allgemeine Botanische Zeitung 2, (Jena)*, **72**, 298–347.

Dixon, J. C., Thorn, C. E. and Darmody, R. G. (1984). Chemical weathering processes on the Vantage Peak nunatak, Juneau Icefield, southern Alaska. *Physical Geography*, **5**, 111–131.

Friedmann, E. I. (1971). Light and scanning electron microscopy of the endolithic desert algal habitat. *Phycologia*, **10**, 411–428.

Friedmann, E. I. and Gulun, M. (1974). Desert algae, lichens and fungi. In Brown, G. W. Jr (Ed), *Desert Biology, 2*. Academic Press, New York, pp. 165–212.

Friedmann, E. I. and Ocampo, R. (1976). Endolithic blue-green algae in the dry valleys: primary producers in the antarctic desert ecosytem. *Science*, **193**, 1247–1249.

Friedmann, E. I. and Weed, R. (1987). Microbial trace-fossil formation, biogenous, and abiotic weathering in the Antarctic cold desert. *Science, N.Y.*, **236**, 703–705.

Friedmann, E. I., Lipkin, Y. and Acampo-Paus, R. (1967). Desert algae of the Negev (Israel). *Phycologia*, **6**, 185–196.

Fry, E. J. (1924). A suggested explanation of the mechanical action of lithophytic lichens on rocks (shale). *Annals of Botany*, **38**, 175–196.

Fry, E. J. . (1926). The mechanical action of corticolous lichens. *Annals of Botany*, **40**, 397–417.

Hall, K. J. (in preparation). The role of wetting and drying in rock breakdown on the Juneau Icefield, Alaska.

Hamelin, L-E. (1964). Le periglaciaire du Massif Juneau en Alaska. *Biuletyn Peryglacjalny*, **13**, 5–14.

Kappen, L., Friedmann, E. I. and Garty, J. (1981). Ecophysiology of lichens in the dry valleys of southern Victoria Land, Antarctica. I. Microclimate of the cryptoendolithic lichen habitat. *Flora*, **171**, 216–235.

Klipfel, P. D. (1981). *Geology of an Area Near Mt. Ogilvie Northern Boundary Range, Juneau Icefield, Alaska.* Unpublished MSc Thesis, University of Idaho, 144 pp.

Linder, G. M. (1981). *Reconnaissance Glacial Geology of Avalanche Canyon, Juneau Icefield, Southeast Alaska.* Unpublished MSc Thesis, University of Idaho, 116 pp.

Marston, R. A. (1983). Supraglacial stream dynamics on the Juneau Icefield. *Annals of the Association of American Geographers*, **73**, 597–608.

Mellor, E. (1922). Vitricolous lichens and the deterioration of church windows. *Revue gènèrale de Botanique*, **34**, 281.

Miller, M. M. (1964). Inventory of terminal position changes in Alaskan coastal glaciers since the 1750s. *Proceedings of the American Philosophical Society*, **108**, 257–273.

Muntz, M. A. (1980). On the decomposition of rock and the formation of arable soil. *Compte rendu Congrès national des Sciences*, **110**, 1370–1372.

Palmer, R. J. (1989). Microbial weathering of building stone. *Abstracts; Biological Conference*, Moscow, 132.

Shenker, A. E. (1979). *Glacial, Periglacial and Cryopedogenic Development of Arctic–Alpine terrains in the C-26 Sector of the Juneau Icefield, Atlin Provincial Park, N.W. British Columbia, Canada.* Unpublished MSc Thesis, University of Idaho, 149 pp.

Vincent, W. F. (1988). *Microbial Ecosystems of Antarctica.* Cambridge University Press, Cambridge, 304 pp.