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Rock mass loss on a nunatak in Western Dronning Maud Land, Antarctica

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ABSTRACT

This paper presents the first rock mass loss data for uncut clasts from continental Antarctica. A rock mass loss experiment using doleritic rock samples was conducted over a seven-year period, between 2008 and 2014, at the Vesleskarvet nunataks, Western Dronning Maud Land. The data show that approximately 10% of clasts suffered a mass loss that is an order of magnitude greater than the remaining 90% of clasts. Thus, the observed rock mass loss is suggested to occur in a series of events that are impossible to predict in terms of frequency and/or magnitude. However, extrapolating from the data obtained during the seven-year period indicates that rates of mass loss are slow and of the order of 1% per 100 years. Direct erosion by wind (including abrasion) as well as mechanical and chemical weathering are suggested to be responsible for rock mass loss. Rock properties, the weathering environment, and a lack of available moisture may be contributing factors to the slow rate of rock decay. This paper suggests that in this area of Antarctica, the slow rate of rock mass loss increases the longevity of existing periglacial landforms such as patterned ground and blockfields, but inhibits development of new patterned ground through the slow production of fines.

INTRODUCTION

Ice-free areas in continental Antarctica are characterized by low air temperatures, strong winds, and a paucity of water in the liquid phase (Matsuoka, 1995). These conditions are conventionally thought to be responsible for slow rock decay. Some studies (i.e., Hall and André, 2001; Bockheim, 2002; Matsuoka et al., 2006; Hall et al., 2008a, 2008b; McKay et al., 2009; Guglielmin et al., 2011) have addressed aspects of weathering in continental Antarctica, but no known studies specifically investigate the rate of rock mass loss. The only known studies on the rate of rock mass loss in the southern polar regions are by Hall (1990), who reported annual mean mass loss rates of 0.02% for freshly cut clasts of different lithologies from Signy Island, Maritime Antarctica, and Sumner (2004), who documented annual mean mass loss rates of 0.02 and 0.1% for naturally shaped gray and black lava clasts on Subantarctic Marion Island. The aim of this paper is to determine the contemporary rate of rock mass loss at the Vesleskarvet nunataks, Western Dronning Maud Land, Antarctica. Determination of contemporary rock mass loss at inland nunataks is important in terms of the production of fines for current pedogenic and periglacial processes as well as existing landform longevity. Even under the extremely harsh climate (i.e., lack of available moisture), the production of fines does occur and may be significant for the facilitation of habitats for biota, which typically colonize the fringes (troughs) of sorted patterned ground in ice-free areas (Lee et al., 2013).

STUDY SITE

Ice-free areas of Antarctica comprise less than 1% of the subaerial extent of the continent (Bockheim and Hall, 2002). Much of the geomorphological research in Antarctica occurs in ice-free areas along the Antarctic Peninsula (e.g., Cofaigh et al., 2014) and in the Dry Valleys (e.g., Speirs et al., 2008) but, due to their geographic isolation, very few studies have been conducted on the nunataks in the inland regions (including Dronning Maud Land) of Antarctica (e.g., Matsuoka et al., 2006; Hedding et al., 2010; Hansen et al., 2013). The conditions on inland nunataks may be more extreme than those found on the peninsula (Walton, 1984) because they are separated from the stabilizing climatic influence of the ocean.

This study was conducted on the Southern Buttress next to the SANAE IV research station at the Vesleskarvet nunataks (71°40′S, 2°51′W) in Western Dronning Maud Land (Fig. 1). This rocky outcrop forms part of the Ahlmannryggen-Borgmassivet Mountains (SASCAR, 1981) and is 160 km inland of the Princess Martha coast of Dronning Maud Land. The main nunatak rises to roughly 850 m a.s.l. and has an exposed surface area of some 22.5 ha. The nunatak is divided into two areas named the "Northern Buttress" and "Southern Buttress," of which the northern is the larger. The average ambient air temperatures measured at Vesleskarvet are –8.3 °C and –21.8 °C for the Austral summer and winter months, respectively (Hansen et al., 2013). The dominant wind direction is from the east and annual average wind speeds approximate 11 m s^{-1}, but gusts of up to 61.9 m s^{-1} have been recorded. Western Dronning Maud Land is described as very arid and receives between 55 and 81 mm of precipitation annually, falling exclusively as snow (Reijmer and van den Broeke, 2001).

The rock exposures at Vesleskarvet comprise homogenous mafic igneous rocks of the Borgmassivet Intrusions, the dominant rock type in the northern Ahlmannryggen (Claassen and Sharp, 1993). These nunataks form part of the Borgmassivet intrusives of the Jutulstraumen Group and are of Mesoproterozoic origin (SASCAR, 1981). The mafic Borgmassivet sill intruded into the Ritscherflya Supergroup at 1107 Ma (Grosch et al., 2007). Steele et al. (1994) indicated that these nunataks have been weathered to a depth of approximately one meter, forming a substratum of large angular boulders. Both buttresses at Vesleskarvet display autochthonous blockfields (Hansen et al., 2013), and rock faces exhibit case hardening. Lee et al. (2013) noted that although liquid water availability is primarily driven by microclimatic rather than by macroclimatic temperature, liquid water is scarce, occurring only during the short austral summer when macroclimatic temperatures are high enough to cause brief periods of snow and ice melt. Nevertheless, the visually limited liquid in summer facilitates biological activity (Lee et al., 2013) and chemical weathering as illustrated by the presence of weathering rinds approximately 0.01 m in thickness (Fig. 2, part A). Weathering rinds are reddish-brown in color and are evident on almost all rock surfaces on the Vesleskarvet nunataks (Fig. 2, part A). Lithosols are found extensively in depressed flat areas throughout the nunatak and in small isolated patches in sheltered areas between rocks.

METHODOLOGY

To initiate the rock mass loss experiment, 74 small uncut dolerite clasts ranging in size from 93 to 318 grams were selected (Fig. 2, part B), dried in an oven, and weighed to obtain their dry mass (Fig. 2, part C). In the austral summer of 2007–2008, these clasts were separated into 8 groups and placed at random locations on the Southern Buttress of Vesleskarvet (Fig. 2, part B). Clasts were then recovered from the field, transported to the research station on a tray, and weighed yearly to determine mass loss over a seven-year period. Several clasts were lost during the study, presumably due to strong winds dislodging them from their sites, and at the end of the experiment 39 clasts remained. The possible displacement of clasts within each study site was not recorded. A control set, compris-

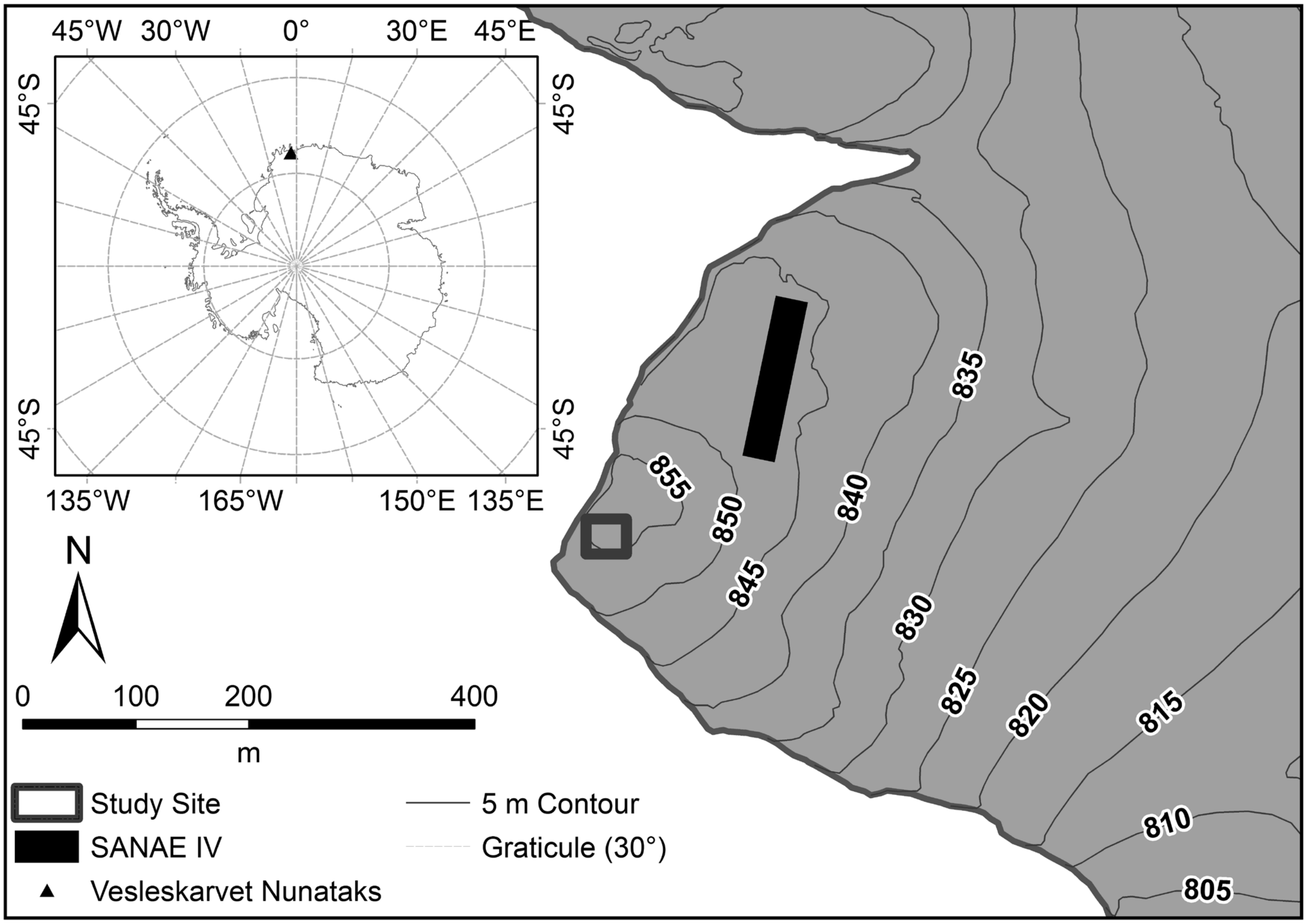

FIGURE 1. Location map of Vesleskarvet, Western Dronning Maud Land, Antarctica.

ing 18 clasts, was also incorporated into the study. The control set of clasts was dried and weighed at the onset of the experiment and only dried and weighed every second year. The clasts were placed in a storeroom in the SANAE IV research station, which represents a relatively stable environment where temperatures range from 18 °C to 22 °C and relative humidity averages 65%. Similar to the rock mass loss experiments conducted by Hall (1990) and Sumner (2004), the dry weight, porosity, microporosity, water absorption, and saturation coefficient of the dolerite clasts were determined (Table 1) at the end of the study using the methods described by Cooke (1979).

Results and Discussion

Over the seven-year study, annual mean rock mass loss was observed to be 0.01%. However, annual mean mass loss from individual clasts varies quite considerably (Table 2). The maximum rate of annual mean mass loss recorded was 0.214% (Table 2). No trend or stabilization of annual rock mass loss was noted, and the data do not suggest that clast weight is related to the rate of rock mass loss. Future studies should also investigate if the rate of rock mass loss is linked to edge length and/or surface area. During the study approximately 10% of the clasts weighed suffered mass loss that is an order of magnitude greater than the remaining 90% of clasts. It is suggested that these clasts have undergone weathering and/or direct erosion by wind (including abrasion). All clasts used in the experiment exhibited weathering rinds of varying thickness (Fig. 2, part A), but no clasts exhibited visual signs of flaking or fracturing during the weighing process. It is suggested that, similar to the observation of Sumner (2004), mass loss occurs on a granular scale. No trend or stabilization of an-

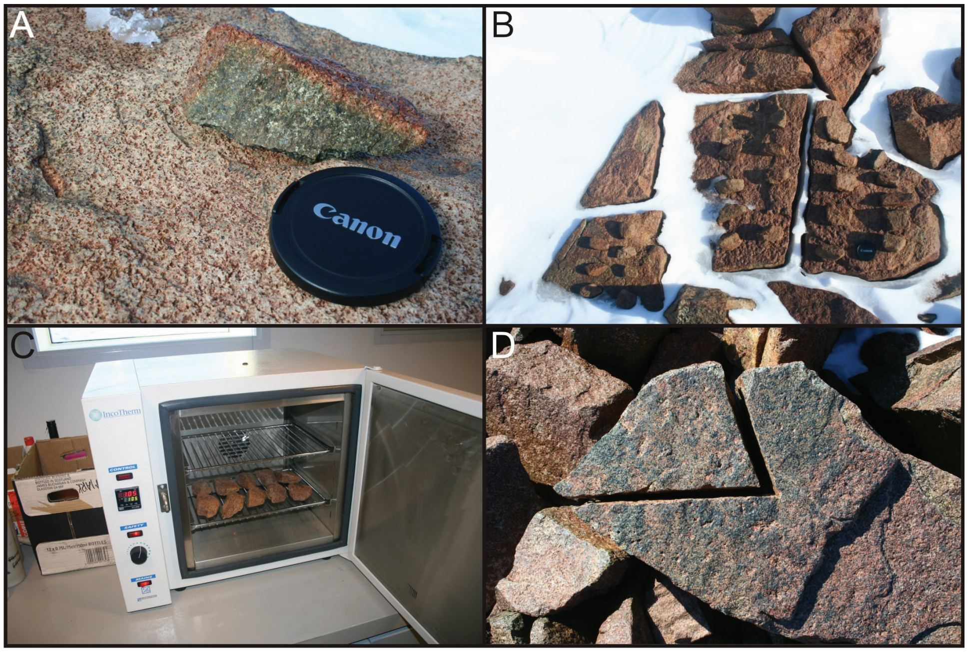

FIGURE 2. Evidence of (A) discoloration of rock surfaces (weathering rinds) indicative of chemical weathering at Vesleskarvet, Western Dronning Maud Land; (B) clasts of varying sizes at one of the random locations within the study site at Vesleskarvet; (C) drying of clasts in the oven during the experiment; and (D) fractures indicating mechanical weathering.

nual mass loss was noted. Mass loss for the control sample of clasts indicates an annual mean mass loss of 0.003% (Table 3).

Extrapolation of rock mass loss suggests that clasts may break down completely in 10,000 years at this location on continental Antarctica. Thus, the longevity of small clasts at Vesleskarvet are an order of magnitude greater than gray lava (basalt) clasts on Subantarctic Marion Island (Sumner, 2004) and "naturally shaped" clasts on Signy Island, Maritime Antarctica (Walton and Hall, 1989). Annual mean mass loss at Vesleskarvet is also twice as slow as freshly cut blocks of various Signy Island lithologies (Hall, 1990). However, the freshly cut blocks used by (Hall, 1990) would not have been chemically weathered and, therefore, would most likely have been more reactive to chemical weathering. Although none of the clasts showed visual signs of mechanical weathering, evidence of chemical weathering (Fig. 2, part B) and mechanical weathering (Fig. 2, part D) were noted on exposed rock surfaces. Thus, the data presented point toward a suite of mechanisms which are responsible for rock mass loss: erosion by the wind (abrasion), mechanical weathering, and chemical weathering. Most of the rock surfaces at Vesleskarvet exhibit weathering rinds that may be the product of past or present climates. These weathering rinds may make the surface less permeable and stronger and thereby slow the weathering process by protecting the underlying rock. Because no obvious visual signs of rock mass loss were evident, granular disintegration is considered the main product. Lichen growth on rocks at Vesleskarvet also provides an indication that biological activity may be responsible for rock mass loss (see Hall et al., 2008a). The slow rate of rock mass loss at Vesleskarvet may be attributable to the inherent rock properties, the long austral winters

TABLE 1

Rock physical properties (Cooke, 1979) of a sample set of dolerite clasts from Vesleskarvet, Western Dronning Maud Land (Adapted from Hansen, 2013).

Rock type—Dolerite		Porosity (%)	Microporosity (%)	Water absorption	Saturation coefficient
	Mean	0.60	82.06	0.57	0.94
	Median	0.53	84.62	0.51	0.94
(*n* = 20)	Std. dev.	0.22	8.63	0.24	0.04

TABLE 2

Mass loss from dolerite clasts between the austral summers of 2007/2008 and 2013/2014.

Sample	2007/2008 Dry mass (g)	2013/2014 Dry mass (g)	Percentage mass loss over 7 years	Total mass loss (g)	Annual mean mass loss (%)	100-Year mass loss (%)
1	304.352	304.260	0.030	0.092	0.004	0.432
2	259.695	259.692	0.001	0.003	0.000	0.017
3	212.277	212.249	0.013	0.028	0.002	0.188
4	240.324	240.247	0.032	0.077	0.005	0.458
5	277.123	277.098	0.009	0.025	0.001	0.129
6	238.102	234.529	1.501	3.573	0.214	21.437
7	286.879	286.848	0.011	0.031	0.002	0.154
8	283.177	282.876	0.106	0.301	0.015	1.518
9	254.538	254.535	0.001	0.003	0.000	0.017
10	297.428	297.361	0.023	0.067	0.003	0.322
11	263.045	262.984	0.023	0.061	0.003	0.331
12	296.542	296.537	0.002	0.005	0.000	0.024
13	250.508	250.465	0.017	0.043	0.002	0.245
14	287.586	287.481	0.037	0.105	0.005	0.522
15	201.286	201.249	0.018	0.037	0.003	0.263
16	224.640	223.878	0.339	0.762	0.048	4.846
17	272.010	271.971	0.014	0.039	0.002	0.205
18	237.744	237.684	0.025	0.060	0.004	0.361
19	249.252	249.183	0.028	0.069	0.004	0.395
20	195.195	195.150	0.023	0.045	0.003	0.329
21	307.294	307.283	0.004	0.011	0.001	0.051
22	170.523	170.512	0.006	0.011	0.001	0.092
23	282.412	282.401	0.004	0.011	0.001	0.056
24	268.069	268.061	0.003	0.008	0.000	0.043
25	238.087	238.008	0.033	0.079	0.005	0.474
26	285.551	285.530	0.007	0.021	0.001	0.105
27	259.004	258.949	0.021	0.055	0.003	0.303
28	205.015	204.961	0.026	0.054	0.004	0.376
29	318.843	318.714	0.040	0.129	0.006	0.578
30	263.822	263.792	0.011	0.030	0.002	0.162
31	198.003	197.787	0.109	0.216	0.016	1.558
32	261.485	261.365	0.046	0.120	0.007	0.656
33	205.753	205.712	0.020	0.041	0.003	0.285
34	163.920	163.910	0.006	0.010	0.001	0.087
35	127.930	127.927	0.002	0.003	0.000	0.034
36	191.664	191.640	0.013	0.024	0.002	0.179
37	243.944	243.912	0.013	0.032	0.002	0.187
38	260.586	260.572	0.005	0.014	0.001	0.077
39	93.660	93.642	0.019	0.018	0.003	0.275
Average	243.007	242.845	0.068	0.162	0.010	0.968
Std. dev.	49.520	49.528	0.242	0.575	0.035	3.457
Max	318.843	318.714	1.501	3.573	0.214	21.437
Min	93.660	93.642	0.001	0.003	0.000	0.017
Range	225.183	225.072	1.499	3.570	0.214	21.421

TABLE 3

Mass loss from the control sample of dolerite clasts between the austral summers of 2007/2008 and 2013/2014.

Sample	2007/2008 Dry mass (g)	2013/2014 Dry mass (g)	Percentage mass loss over 7 years	Total mass loss (g)	Annual mean mass loss (%)	100-Year mass loss (%)
1	271.543	271.495	0.018	0.048	0.003	0.25
2	251.819	251.781	0.015	0.038	0.002	0.22
3	274.234	274.219	0.005	0.015	0.001	0.08
4	268.191	268.158	0.012	0.033	0.002	0.18
5	263.953	263.911	0.016	0.042	0.002	0.23
6	294.081	294.079	0.001	0.002	0.000	0.01
7	223.608	223.603	0.002	0.005	0.000	0.03
8	296.361	296.297	0.022	0.064	0.003	0.31
9	258.071	258.008	0.024	0.063	0.003	0.35
10	205.766	205.73	0.017	0.036	0.002	0.25
11	255.912	255.862	0.020	0.050	0.003	0.28
12	252.667	252.606	0.024	0.061	0.003	0.34
13	230.829	230.724	0.045	0.105	0.006	0.65
14	209.036	208.998	0.018	0.038	0.003	0.26
15	292.765	292.649	0.040	0.116	0.006	0.57
16	309.322	309.289	0.011	0.033	0.002	0.15
17	202.468	202.384	0.041	0.084	0.006	0.59
18	319.210	319.185	0.008	0.025	0.001	0.11
Average	259.991	259.943	0.019	0.048	0.003	0.270
Std. dev.	35.213	35.217	0.013	0.031	0.002	0.182
Max	319.210	319.185	0.045	0.116	0.006	0.650
Min	202.468	202.384	0.001	0.002	0.000	0.010
Range	116.742	116.801	0.045	0.114	0.006	0.640

where sunlight is absent and when temperatures remain relatively constant at −15 °C, and/or the paucity of available moisture. This suggests that longer-term studies should be set up to determine the role, frequency, and magnitude that various processes may play in the breakdown of rocks in this region of Antarctica. In particular, studies should focus on the rates of weathering of clasts in a substratum and chemical weathering, because rock temperatures can reach up to 30 °C during the austral summer (unpublished data) where liquid water is present to facilitate rock mass loss.

The availability of fine material is inherently necessary for the development of sorted patterned ground. However, fines in existing sorted patterned ground may also represent remnants of rock breakdown under different environmental conditions. The fringes of polygons represent zones where finer eolian and frost-sorted material can accumulate as sorted patterned ground develops (see Kessler et al., 2001). Lee et al. (2013) suggested that the most important environmental variable, maximum soil moisture content that is linked to fines, can account for as much as 80% of the variance in the abundance of mites in polygons on the Jutulsessen nunatak, Western Dronning Maud Land. Barrett et al. (2004) reported that polygon centers contain the highest abundance of species and biodiversity at sites in the McMurdo Dry Valleys, Antarctica. Therefore, the current production of fines from rock mass loss in this area can create habitats for invertebrates and may be significant because fine material should retain moisture and facilitate chemical weathering in an extremely dry environment.

CONCLUSION AND FURTHER RESEARCH

This note presents the first rock mass loss study for continental Antarctica. Extrapolation of rock mass loss suggests that clasts may breakdown completely in 10,000 yr. Long-term rock mass studies should be set up to specifically investigate the frequency and/or magnitude of the rate of decay as well as the physical characteristics (i.e. weight, edge length, surface area) and chemical composition of clasts that may be linked to the rate of rock mass loss. The documented rate of rock mass loss is particularly slow when compared to studies from the Subantarctic and Maritime Antarctic, and will limit the production of fines and inhibit periglacial and pedogenic processes. The slow rate of rock mass loss increases the longevity of existing periglacial landforms such as patterned ground and blockfields. Areas that comprise fines may represent preferential locations for colonization by invertebrates but the linkages between the prevalence of fines and soil moisture should be investigated as well as the environmental controls for the abundance of species and biodiversity in continental Antarctica.

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