

A METHOD FOR THE EXTRACTION AND ANALYSIS OF SOLUTES FROM ROCK SAMPLES WITH SOME COMMENTS ON THE IMPLICATIONS FOR WEATHERING STUDIES: AN EXAMPLE FROM SIGNY ISLAND, ANTARCTICA

K. J. HALL

Geography Department, University of Natal, Pietermaritzburg, South Africa

A. A. VERBEEK

Chemistry Department, University of Natal, Pietermaritzburg, South Africa

and

K. I. MEIKLEJOHN

Geography Department, University of Natal, Pietermaritzburg, South Africa

ABSTRACT. A new method is presented that allows determination of the solutes available inside a rock sample. Such results have not previously been available and yet they are of great importance for investigation of both chemical and mechanical weathering. The data also provide a useful input into studies of mineral cycling. The findings from this pilot study suggest that chemical weathering on Signy Island is in a very early stage. The indicated range of molarity for NaCl (0.34–0.57) is exactly that suggested by some workers to be most potent in aiding freeze–thaw action.

INTRODUCTION

A major problem in weathering studies is the accurate assessment of rock water content (McGreevy and Whalley, 1985; Hall, *in press a*) for this is an important control of both physical and chemical weathering. In addition, knowledge of the chemical composition of the rock water is extremely important as it helps determine what chemical reactions have taken place within the rock (Selby, 1982). Further, the types and amount of salts present in the aqueous content have a direct control on the rate, and the actual mechanism, of both freeze–thaw and salt weathering (Hallet, 1983; Williams and Robinson, 1981). Yet, despite its obvious significance, the analysis of interstitial water from rocks is limited, as far as the authors know, to one sample from chalk undertaken by Kinniburgh and Miles (1983).

Whilst there are data available on the chemistry of precipitation and soil moisture content (Walton, 1984; O'Brien and others, 1979; Mumford and Peel, 1982; Dixon and others, 1984) and of run-off in cold environments (e.g. Reynolds and Johnson, 1972) these do not take cognisance of changes that may take place within the rock. For instance, the interaction of water availability, rock properties and chemical weathering could give solute accumulation within the rock or may result in the flushing-out of the weathering products in solution. Such information provides essential data for the investigation of mineral cycling and pedogenesis as it aids quantification of the chemical input to the soil directly from the rock rather than as a product of soil processes *per se*. In addition, the role of chemical weathering in cold climates is gaining significance for localities where adequate water and hydrogen ion supply are available (Dixon and others, 1984; Thorn, 1976; Dixon, 1983) and so there is a pressing need for information on rock water chemistry. This same information

is also urgently required for the undertaking of laboratory simulations. Fahey (1985, p. 103), in trying to determine what solutions to use for laboratory simulation of frost and salt weathering, sums up the present situation: 'Unfortunately there are virtually no published data available on the concentration of salt solutions in low temperature environments.' Consequently discrepancies in simulated weathering experiments (e.g. Williams and Robinson, 1981; McGreevy, 1982) are largely a result of the lack of knowledge on what salt concentrations to use in the experiments.

The aim here is to present a new, relatively simple, method whereby the solutes from inside a rock may be analysed. The results of four pilot tests are given and then considered in terms of their implications for weathering in the maritime Antarctic.

STUDY AREA

The samples were collected from Signy Island (60° 43' S, 45° 38' W), one of the smaller islands in the South Orkney Islands group (Fig. 1). Geologically the island comprises metamorphosed sediments, primarily quartz-micaschist but with smaller areas of amphibolites, marbles and quartzites (Mathews and Maling, 1967; Storey and Meneilly, 1985). The island is small in size, about 8 km north-south and 4.8 km east-west, with an area of 19.94 km² and rising to a height of 279 m. About one-third of the island is currently ice covered but much of the remainder is subject to long-term snow cover. Precipitation is approximately 0.4 m yr⁻¹ but with running water in summer mainly as a result of snow and ice melt.

METHODOLOGY

Samples of quartz-micaschist were collected from the cliff-face and scree at the base of Factory Bluffs in Factory Cove (Fig. 1). The cliffs are north-facing and only a short distance (c. 20 m) from the sea. Upon collection the rocks were sealed in several plastic bags and returned to the island laboratory. A sample of snow, that had fallen during the preceding 24 h, was also collected from the surface of the scree for analysis.

Laboratory Procedure

Upon return to the island laboratory the rocks were removed from their bags and weighed. They were then dried for 72 h at 105 °C to drive-off any moisture and leave all solutes as precipitates. The rocks were then sealed in bags and returned to South Africa, where they were then weighed, crushed and milled to a coarse powder. A subsample of 50 g of the powder was added to 50 ml of deionized water; the whole was then shaken for 15 min to dissolve all soluble material. The aqueous solution was then filtered under vacuum and forced through a 0.4 µm filter to remove any fine material in suspension. One millilitre of concentrated HNO₃ was added to the filtrate to dissociate the cations from the salts. The resulting sample was then analysed for the elements Ca, Na, Mg, K, Si, Fe and Cu using an Instrument Laboratory Plasma-100 sequential inductively coupled Argon plasma emission spectrometer.

Sub-samples of the rocks were analysed, following the procedure of Cooke (1979), for their porosity, water absorption, capacity, saturation coefficient and microporosity, as all of these properties are related to water availability and movement within the rock. Analysis of the chemical composition of two quartz-micaschist samples was undertaken by means of electron excitation X-ray fluorescence spectrometry (Walton, pers. comm.) whilst X-ray diffraction, using peak height percentages, was undertaken on the four samples to obtain the percentage composition of plagioclase, silica, mica and chlorite.

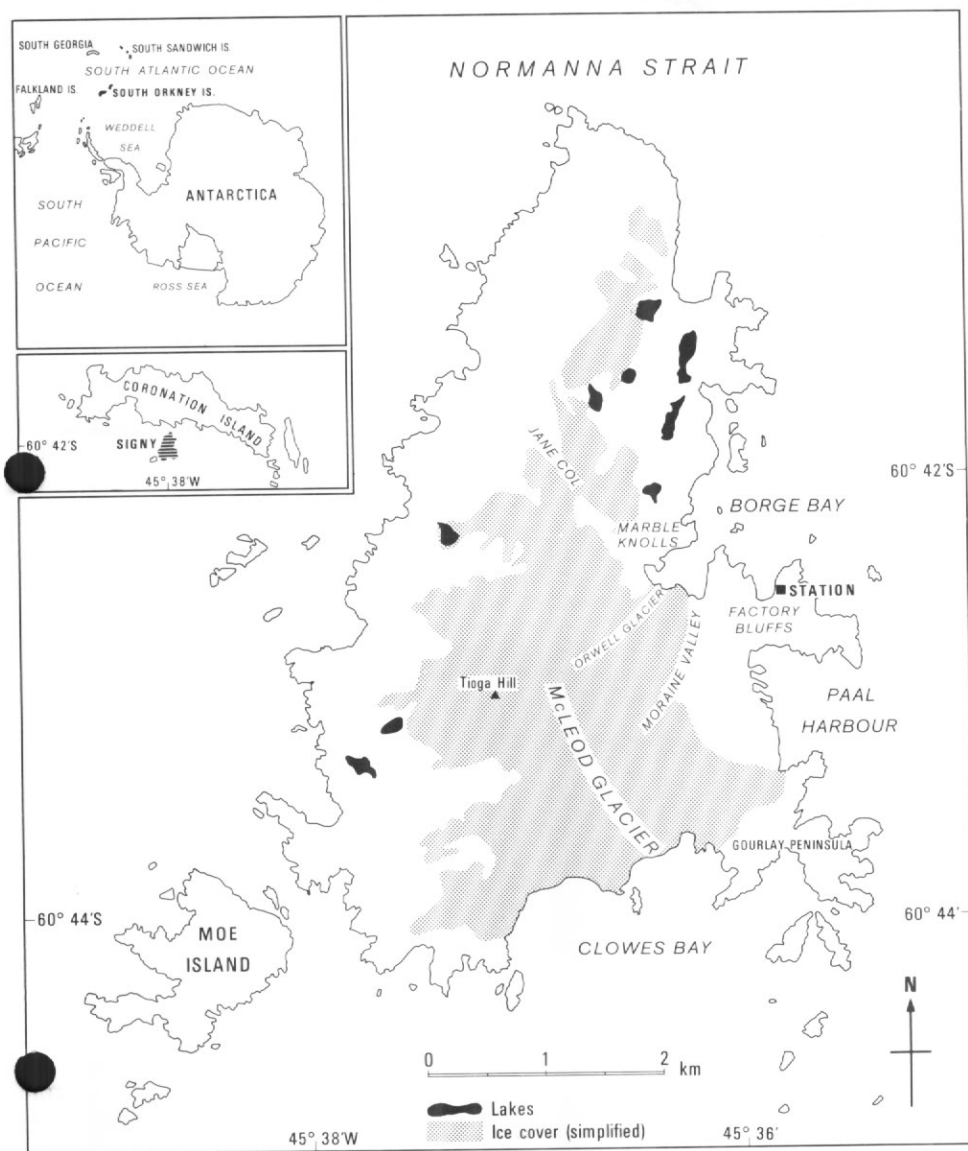


Fig. 1. Location map for Signy Island.

RESULTS AND DISCUSSION

Results of the spectrometer analyses of the rock solutes and the snow sample, together with the properties of the rocks, are presented in Table I. X-ray diffraction analyses of the four rock samples are given in Table II and the Betaprobe results for two schist samples are shown in Table III. Whilst it must be considered that water from sea spray, if it entered the rock, could introduce salts, particularly those of Na and Mg, there is, nevertheless, a noticeable difference between the solute content of the snow and the rock. Whilst the origin of the salts (i.e. externally introduced or as a product of weathering) is important with respect to comprehension of chemical

Table I. Rock properties, moisture content and spectrometer analysis of solutes for four Signy Island schist samples.

Property	Sample				
	1	2	3	4	Snow
Porosity (%)	2.63	1.48	2.01	— ¹	—
Water absorption capacity (%)	2.16	0.99	1.85	—	—
Saturation coefficient	0.82	0.67	0.92	—	—
Microporosity (%)	75.0	58.3	44.0	—	—
Microporosity M ¹²	1.97	0.86	0.89	—	—
Rock dry weight (g)	144.7	227.7	330.0	484.0	—
Moisture content (g)	0.80	1.30	2.0	1.98	—
Moisture content (%) ³	0.55	0.57	0.61	0.41	—
Element (p.p.m.)					
Ca	9.1	10.8	6.8	6.6	0.56
Na	65.1	74.8	62.9	32.0	2.55
Mg	2.47	2.52	1.23	2.16	0.12
K	41.7	67.9	46.8	41.6	0
Fe	0	0.12	0	0.37	0
Si	1.0	1.4	1.8	2.0	0
Cu	0.07	0.10	0.14	0.20	0.016

¹ Rock crushed before these properties found.² Microporosity M¹ is microporosity as per cent of total bulk volume.³ Moisture content as a percentage of rock dry weight.

Table II. X-ray diffraction analyses to show the percentage mineral composition of the four rock samples detailed in Table I.

Rock component	1	2	5	6
Plagioclase	37 ¹	48	50	31
Silica	22	26	33	38
Mica	27	20	15	29
Chlorite	14	6	2	2

¹ Peak height percentages.Table III. Betaprobe analysis of two characteristic schist samples from Signy Island.¹

Compound	Rock	
	A (%)	B (%)
SiO ₂	60.0	64.3
Al ₂ O ₃	15.4	15.2
Total Fe as Fe ₂ O ₃	7.52	7.29
MgO	2.69	2.90
CaO	5.04	1.94
Na ₂ O	3.48	2.28
K ₂ O	2.00	2.64
MnO	0.12	0.10
TiO ₂	1.28	0.73
P ₂ O ₅	0.24	0.17
F	0.06	0.06
S	0.04	—

¹ Data supplied by Walton (pers. comm.) and do not represent analyses of samples 1–4 shown in Tables I and II.

weathering processes and rates, it is rather what salts are available, and in what amounts, *within* the rock that are pertinent to mechanical weathering considerations (see below). One factor that introduces an error into the spectrometer analyses is that some Na and K may be liberated from the crushed plagioclase and/or K-feldspar during the dissolution treatment. This, though, is considered to be minimal as comparison of results of different shaking times up to one hour showed no significant differences in solute content. If highly accurate results are required then a similar amount of feldspar to that found in the rock could be subject to the same treatment, the solution analysed and the resulting p.p.m. of Na and K subtracted from that found for the crushed rock. In this pilot study this was not possible.

Utilizing the known weight of the original rock and its moisture content, it was possible to change the data units from p.p.m. to moles. Since 1 mole Na derives from 1 mole NaCl the molarity of NaCl for the four samples was calculated (0.57, 0.51, 0.45 and 0.34 M for samples 1–4 respectively). This allowed a determination of the salt most active in mechanical weathering in units which allow comparison with simulation studies of other workers. Some authors (e.g. Fahey, 1985) utilized MgSO_4 for polar weathering simulation but the low molarity found here (0.012, 0.018, 0.027 and 0.04 M for samples 1–4) suggests it is not an active salt in this particular maritime Antarctic environment.

It is thought that Ca and Na are derived from the plagioclase, which is found in high concentrations (Table II) and, compared to the other minerals, is relatively soluble. The Mg comes from the chlorite and the K is derived from the micas. Si could come from any of the minerals listed in Table II and may, in fact, be derived from them all. The Fe could come from either the chlorite or the micas whilst the origin of the Cu is uncertain. Overall, the impression is one of a very early stage in chemical weathering, particularly as extensive leaching would have given higher Si values. This conclusion is borne out by the results of tests on the mechanical strength of the rock (Hall, *in press b*) which, on the engineering grade classification of Day (1980), classify them as only 'slightly weathered'.

It is worth noting that McGreevy (1982), in experiments on rock breakdown due to the effects of freezing salt solutions, found that the greatest destruction was associated with 0.25–0.5 M solutions of NaCl. Exactly how and why such a concentration may abet freeze-thaw weathering is uncertain, and it could even be that the damage occurs due to hydration ($\text{NaCl} \rightarrow \text{NaCl} \cdot 2\text{H}_2\text{O}$) at $+0.2^\circ\text{C}$ (McGreevy, 1982). However, Hallet (1983) suggests that at low solute concentrations the freezing temperature is lowered and so the unfrozen water content is increased, as too is water mobility at sub-freezing temperatures. By increasing water transport to freezing interfaces, crack growth speed would be accelerated and thus more rapid destruction would occur. Whatever the actual mechanism, the importance of this technique is that it has, for the first time, allowed some estimate of the actual salt content of the rock to be determined. Thus, laboratory simulations can now be undertaken with a closer approximation to reality in an endeavour to elucidate what processes are operative.

CONCLUSIONS

A new method for determining the solute content of rocks is presented. In its current form it is not a high precision technique but refinements could be added to improve accuracy. Nevertheless, these data are unique and, as such, give a valuable guide to both the understanding of weathering processes (particularly freeze-thaw and salt weathering) on Signy Island and to what salt concentrations to use in laboratory simulations of mechanical weathering. The solute concentrations that have been found

suggest limited chemical weathering of the rock, which is perhaps to be expected from a cool Antarctic environment and rocks with low water contents, and this is consistent with the findings of little diminished rock strength. With respect to mechanical weathering, the analyses show NaCl to be the dominant salt and its concentration to be within the range suggested to be the most effective in aiding freeze-thaw. Upon the encouraging basis of these preliminary findings further experiments are planned to enlarge the data base to a statistically valid size.

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