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Antarctic rock weathering simulations: simulator design, application and use

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Abstract: The design of a computer-controlled climatic simulation cabinet used for mechanical weathering studies on Antarctic rocks is described. It is argued that if the results of simulations are to be applicable to field situations they should be firmly based on field environmental conditions. Some weathering results from a laboratory simulation based upon microclimatic data collected from the maritime Antarctic are presented and it is shown that they could not have been obtained from field measurements alone. Further simulation studies are required for the Antarctic and it is argued that the nature of Antarctic research is such that it is particularly conducive to this type of approach.

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Introduction

Although researchers in the Antarctic have recognized the role of weathering in landform formation, they have not undertaken simulations as an aid to determining either process operations or rates. Despite their apparent simplicity, weathering simulations are fraught with difficulties and practical problems. As Thorn (1988, p. 13) points out '... laboratory experiments are ultimately only worthwhile if it can be shown that they mimic natural conditions successfully' and that 'the general validity of laboratory experiments is open to question because of the scale of these experiments'. Thus, although the usage in freeze–thaw simulations of the idealized broad climatic themes of 'Icelandic' and 'Siberian' cycles (e.g. Tricart 1956) facilitates comparison of results, they may be of little significance if these cycles do not reflect the field situation. As a consequence it may be misleading to attempt to apply laboratory-derived results back to the field (McGreevy & Whalley 1982). Ultimately, it is the deficiency of field data on interstitial rock moisture content, and its chemistry, together with knowledge of rock temperatures, that precludes the running of satisfactory simulations of temperature-controlled mechanical weathering processes (McGreevy & Smith 1982, Kerr *et al.* 1984, Thorn 1988).

In an attempt to overcome many such problems in the maritime Antarctic, a combined field and laboratory investigation of mechanical weathering processes was initiated (Hall 1986*a*) as a part of the 'Fellfield Ecology Research Programme' undertaken by the British Antarctic Survey (BAS) on Signy Island, South Orkney Islands (60°43'S, 45°38'W). To ensure that the simulations would accurately replicate the field conditions, information was obtained on the geology (Storey & Meneilly 1985), the field microclimate of individual rocks (Walton 1977, 1982, unpublished), rock moisture content and the rock properties affecting this (Hall 1986*a*), interstitial rock water chemistry (Hall *et al.* 1986), and rock strength (Hall 1986*b*, 1987). In addition, continuing field experiments, including the daily monitoring of changes in mass of a rock tablet as an indication of moisture content changes and weathering rates, provided base-line information for the continued refinement of the simulations (Hall 1988*a*). In the laboratory, the utilization of relatively large rock samples (up to 25 kg) partly reduces problems arising from the use of only hand-size specimens (Thorn 1988). The monitoring of internal rock temperatures overcomes the problems identified by Jerwood *et al.* (1987) of how well the external temperature cycles are reflected in actual rock temperatures.

The simulator

Laboratory simulations have used a great variety of equipment, some very sophisticated and others based on domestic appliances. Often only limited information has been given about the equipment used (Table I); yet the equipment itself may well be a major determinant of the type of simulation possible (Jerwood *et al.* 1987). In addition, the lack of equipment specifications makes it difficult for others to build simulators which have some degree of comparison with those already in use. The present study used a purpose-built simulation cabinet.

The basic design specifications required that:

a. it could work in the temperature range +70°C to –50°C,
b. it would allow sequences of temperature cycles of a wide range of duration, magnitude, frequency and rate of change,

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Table I. Simulator specifications.

	Wiman 1963	Potts 1970	Brockie 1972	Steijn 1979	Fahey 1983	Lautridou & Ozouf 1982	Swantesson 1985	Pécsi 1987	Jerwood *et al.* 1987	Matsuoka 1988	Hall 1986*c*
Adapted commercial equipment		?	✓		✓		?	?		?	
Purpose built	(✓)	?		✓*1		✓	?	?	✓*1	?	✓
Automatic	✓	?		(✓)	?	✓	?	?	✓	?	✓
Manual		?	✓		?		?	?		?	
Rate of change of temperature control	?	(✓?)	✓	?	?	(✓)	?	?	✓	(✓)	✓
Cabinet temperature sensor	(✓)	✓	✓	?	?	✓	?	(✓)	(✓)	✓	✓
Sample temperature sensors	✓	(✓)	✓	?	?	✓	?	?	✓	✓	✓
Automatic sensor logging	✓	(✓)	✓	?	?	✓	?	?	✓	✓	✓
Manual sensor reading				?	?		?	?	✓		
Precision of equipment	?	±1.0°C	±0.75°C	?	?	?	?	?	±0.5°C	?	±0.25°C
Humidity sensor	✓	—	—	?	(✓)	?	(✓?)	?	?	?	✓
Humidity control	(No)	—	—	?	No	?	No	?	?	?	(✓)
Moving air conditions	(No)	—	—	?	✓	?	?	?	?	?	✓
Infra-red lamp facility	—	—	—	?	(✓)	?	?	?	?	?	✓
Ultrasonic testing	—	—	—	?	—	✓	?	?	?	(✓)	✓
Other testing	—	—	—	?	—	?	?	?	?	✓	✓

*1 the name of the equipment is specified; manufacturers could be consulted for details
(✓) by implication or similar specifications
? does not imply that facility does not exist but that no information is available

c. data output would be displayed on both VDU and printer and stored on disk
d. data could be read at varying pre-specified intervals (range 5 s to 99 min) throughout the cycle sequences,
e. facilities would be available for a range of sensor types,
f. a feedback system continuously checked the programmed sequence and instituted corrective action where necessary,
g. programming (in Basic) was very simple,
h. the machine needed minimal attention,
i. mechanical and electronic equipment protection be built-in,
j. data output contained experiment time, programmed status and actual status together with other sensor data outputs.

Based upon the above broad specifications, a cabinet has been built (Fig. 1) utilizing a Commodore 64 PC which, via additional hardware, acts as the central control unit (Fig. 2). The PC also provides the facility for the writing, storing and input of the main control programmes. The programmed temperature is updated every 10 s, compared with the actual cabinet temperature and then a power controller adjusts the heating or cooling.

Output from the six thin film platinum resistance temperature sensors are sequentially selected and converted into digital values which are stored in the PC. Information from the humidity sensor is converted to a linear analogue output and switched into the analogue to digital converter at the appropriate time. A humidity controller is also available but is not at present in use. Output from the 'Pundit' ultrasonic test equipment is converted into a linear pulse width voltage signal and switched into the analogue to digital converter. Signals from the 'Opticat' fibre optic crack detection system are routed back into the PC input port and checked every 10 s for any change. A variable infra-red lamp controller to supply surface heating can be activated via software control. If an 'out of range' condition should occur for any reason for a period greater than 3 min then the whole system is automatically shut down.

The cabinet itself is constructed with an outer body of 'Zintex' and an inner shell of Type 316 stainless steel (with argon welded seams to make it watertight), with 100 mm of expanded polystyrene foam between the two as an insulator. Refrigeration is provided by a 1-HP compressor utilizing 1 kg of Freon 502 as refrigerant. The liquid 502 is divided into two streams (Fig. 3), one passing through an expansion valve into 6 m of 10-mm diameter copper tube, supported in wooden slats, that rests upon the base of the box and provides the ground cooling. This is supplemented by the second stream that gives, aided by a fan, air cooling. Defrosting of the air chiller is achieved by hot gas injection and this process is initiated by the PC every 6 h for a period of 7 min. Heating is provided by a commercially available heating element whose power output is regulated by the PC and which can be balanced against the cooling system.

In this way all of the original design requirements have been achieved and an example of a programme sequence, together with a typical print-out, are shown in Fig. 4. The incorporation of ultrasonic equipment facilitated continuous,

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Fig. 1. View of simulation cabinet identifying the main components.

non-destructive monitoring of changes in certain rock properties (e.g. elasticity, cracks, moisture status) during the simulation (Hall 1988*b*). The fibre optic crack detection system not only showed when failure occurred but also, by means of a laser beam passed down the optic fibre, where and in what multiples cracking took place (Hall 1988*c*). Overall, the cabinet overcomes a number of the shortcomings of many previous units. Not only can any number of highly complex cycles be replicated (driven if required by data directly logged in the field) and data collected during the run at suitable acquisition times, but the read-out indicates how well the machine replicates the programmed cycles. In addition, the ability to heat samples by means of infra-red lamps overcomes problems associated with thermal fatigue simulations (Cooke 1979) and proves especially valuable for the investigation of solar heating effects on rocks at low temperatures. By running the simulations with large samples at field moisture and solute status, and from data logged in the field, it is possible to offer a close approximation to a natural environment

Results and discussion

Antarctic weathering studies have largely concentrated on the cold and very dry ice-free valleys and mountains of the continent (Campbell & Claridge 1987). As a counterpoint to this, the present studies aimed at investigating weathering processes in the warmer, wetter and biologically active maritime Antarctic. Process investigations under controlled conditions are an essential component of this, complementary to the field experiments. Indeed, simulation studies can produce data which would be impossible to obtain in the field.

Initial simulations were directed towards the influence of schistosity upon freezing, the effects of different moisture and solute contents, the interaction of salt weathering and wetting and drying with freeze–thaw, the influence of omni- and unidirectional freezing plane penetration, and the nature and rate of production of weathered material. Data were also obtained on the rate of change of temperature inside the rock during different warming and cooling conditions, the temperature at which the ice into water phase change took place, and the occurrence of acoustic emissions during rock freezing. Although some of the results of these simulations have already been reported in detail elsewhere (Hall 1986*c*, 1988*b*, 1988*c*) they are summarized here to illustrate the value of process studies of this type in investigations of polar and alpine weathering.

Internal rock temperature data show that not only is the rate of temperature change largely controlled by the amplitude of the freezing event but that in schistose rocks it can be up to five times faster when schistosity parallels the freezing front than when it is normal to it. It would thus appear that the attitude of schistose rocks and the amplitude of the freezing event are both important and interrelated factors. This in turn leads to the distinction in weathering rates found for unidirectionally (open system) and omnidirectionally (closed system) frozen rocks. The latter, which also often attain a high moisture content (Hall 1986*a*), may experience different responses to freezing (e.g. undergo hydrofracture) than in the open system freezing, and thus simulations utilizing omnidirectionally frozen material should not use the results as an analogue for the cliff-type open systems. Weathering rates for unidirectionally frozen rocks were found to be as much as 5800% slower than for the

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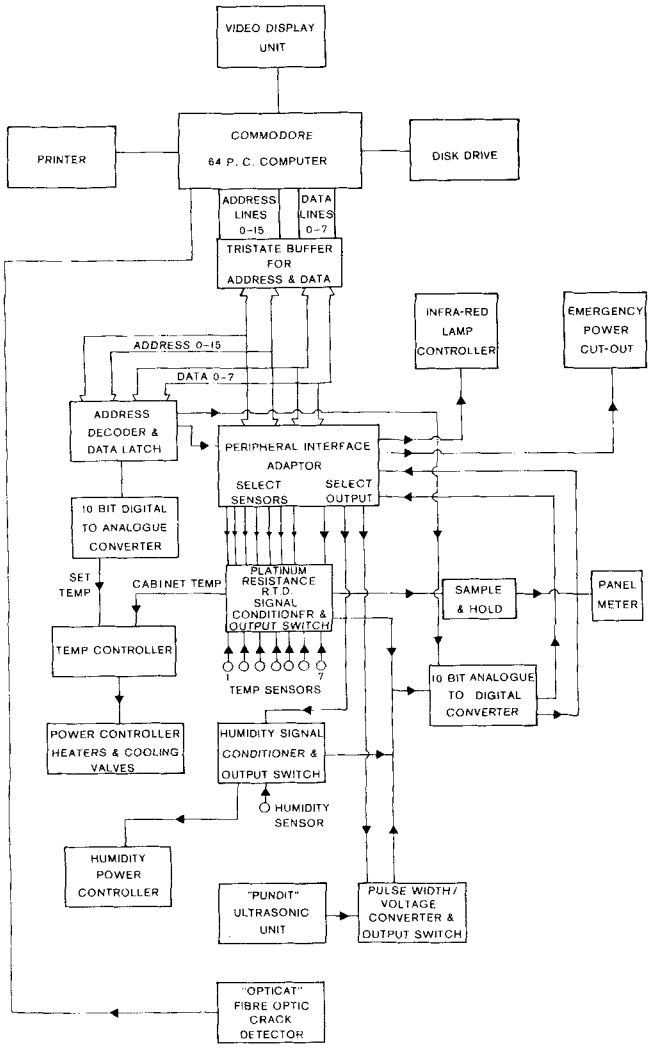


Fig. 2. Circuit diagram of simulation cabinet control system.

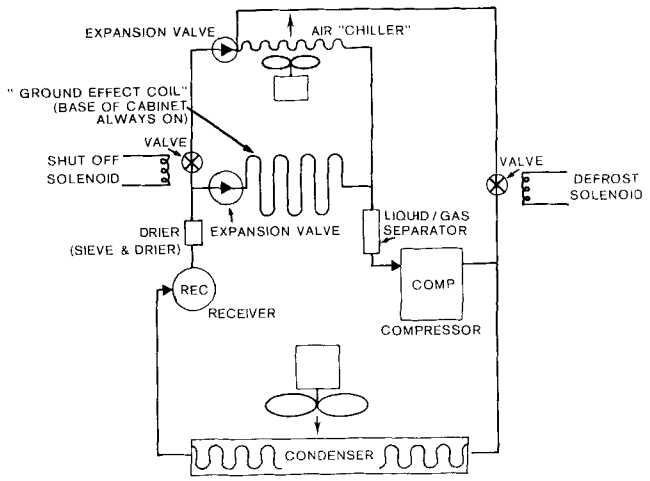
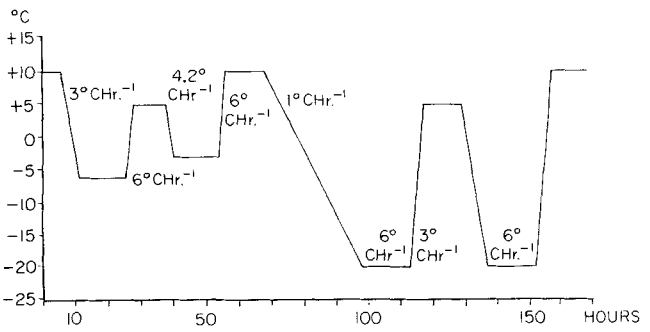


Fig. 3. Refrigeration system of simulation cabinet.



Time	Set °C	Cab °C	S.1 °C	S.2 °C	S.3 °C	S.4 °C	S.5 °C	S.6 °C	Hum. %	USc µs	Row
Col. 1	2	3	4	5	6	7	8	9	10	11	
02:36:00	-6.0	-5.6	-0.7	+0.0	-0.7	-0.3	-4.5	-4.6	36	23.7	240

Where Col. 1 = actual time, Set = programme temperature (°C), Cab = actual cabinet temperature (°C), S1–S6 = temperature sensors 1–6 (°C), Hum = cabinet humidity (%), U/Sc = ultrasonic velocity (µs), Row = data row number.

Fig. 4. A typical programme sequence together with a line of output data.

omnidirectionally frozen, wetted rock subjected to the same temperature fluctuations.

The actual nature of the water to ice phase change that takes place inside the rock was found to vary in response to particular combinations of rock moisture content, solute concentration, freeze amplitude and rate of change of temperature. Three types of phase change were monitored:

a. a rapid, large-scale (≥ 80% of the moisture that would freeze) transformation,
b. a slow, progressive freeze, and
c. a relatively rapid, progressive freeze (intermediate between a and b).

The first type was encountered during relatively slow rates of fall of temperature, the second during higher rates of change, and the third when high saline rock moisture conditions existed irrespective of the nature of the thermal change. It was also found that, for the smaller amplitude freezes (i.e. down to *c.* –6°C), it was necessary for the maximum subzero condition to be maintained for at least 10 h before a phase change took place in the rock. This data is not only valuable with respect to interpretation and application of field microclimatological information but it also has application for theoretical models of weathering (Hallet 1983) in which certain responses are hypothesized to result from specific climatological conditions. Salt content, and thus the potential for combined freeze–thaw and salt weathering (Williams & Robinson 1981, McGreevy 1982), was found to

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influence the rate of rock breakdown as well as the freezing point depression and the temperature of the ice to water phase change (–0.7°C to –1.9°C).

Within the present technological and logistical constraints of Antarctic research, little, if any, of the laboratory findings briefly cited above could have been obtained by means of field investigation. However, by using simulations firmly based on field conditions, it is possible, particularly with field experiments to act as controls, to apply many of the laboratory results back to the field.

Future use

Why should simulations be so valuable to Antarctic studies? Firstly, the slowness with which many weathering processes operate due to the paucity of moisture and the long periods of subzero temperatures makes some field studies impractical. The time-compression ability of the simulation thus takes on a special significance. Secondly, simulation also permits investigation of the potential geomorphic effects of particularly severe (and thus potentially hazardous) climatic conditions. Thirdly, by means of simulations it is possible to investigate the detailed relationships between the various weathering processes. A particularly good example is the role of thermal fatigue initiated by solar heating of rock surfaces during times of severely subzero air temperatures, and the associated thermal strains introduced when that heat source is instantaneously removed by shadow effects. Finally, logistical constraints often preclude frequent visits to particular field sites; simulations backed up by continuous unattended field experimentation can provide a strong framework for weathering studies in remote regions.

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