A provisional method for assessing the impact on, and recovery of, Antarctic Desert Pavements from human-induced disturbances

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Abstract
A set of criteria were developed to quantify the relative stage of desert pavement recovery in the Ross Sea region of Antarctica. The innovative desert pavement classification system was formulated based around a number of distinguishing morphological features that change over time as the pavement re-establishes and stabilises. Features included clast characteristics, such as embeddedness, impressions and attributes to describe clast characteristics (e.g. ventifacted, pitted); surface colour contrast; degree of deflation; varnish; pavement crust coherence and thickness; nature of pavement armour (packing and % of surface armoured); presence of salt coatings on rock undersides, as well as general surface stability (e.g. evidence of subsidence, melt, recent disturbance, and concentrations of salt).

In year one (2008/2009 summer season) of a two year study the parameters were measured experimentally at five sites at Crater Hill and the vicinity of Scott Base, Ross Island. Sites had been disturbed by activities such as bulldozer scraping for road-fill and contouring for infrastructure at times ranging from one week to 50 years prior to assessment. The initial study sites were re-examined in 2009/2010 to test for repeatability and also the extent of visible recovery; and new sites were classified in the McMurdo Dry Valley region. Sites included previously disturbed sites at Marble Point, Lake Vanda in the Wright Valley, and Cape Roberts.

Pavement regeneration and rates of recovery have not previously been studied in the *polar* desert realm. The ability to predict the rate of recovery from disturbance on a range of surfaces assists with assessing the potential impacts of proposed activities in the Antarctic environment. Given knowledge of the site parent material, the application of the criteria showed it was possible to estimate the stage of desert pavement rehabilitation at each site. The system can also potentially be used to estimate the number of years since the desert pavement disturbance occurred.

Keywords
Antarctica, polar desert, desert pavement, human disturbance, recovery.

Introduction
Desert pavements are prominent features of hot arid and polar arid landscapes. Occurring worldwide, pavements are commonly found on gentle sloping sites where vegetation is minimal to non-existent and precipitation is scarce, such as areas in the southwestern U.S.A (McFadden *et al*. 1987) and the McMurdo Dry Valley region of the Antarctic continent. Pavements play an important role in the desert system, acting as protective armour to stabilize both the slope and the soil.

Mature, undisturbed Antarctic desert pavements are typically characterised by a layer of gravel, cobble, and boulder sized rock material; often platy, ventifacted, and coated with desert varnish. Clasts are embedded into a finer matrix; and their undersides are often coated in salts. The clasts are but are not usually strongly cemented to one another or the substrate beneath. Pavement surfaces in Antarctica are consequently easily disturbed by man and machinery, with human impacts commonly including foot traffic, tyre impressions, and bulldozer blade scrapes. Moreover, the prevailing cold desert conditions of the Antarctic continent result in naturally slow recovery rates (Campbell *et al*. 1993); consequently desert pavement at some sites has a low rehabilitative capability following disturbance.

Methods
During the 2008/2009 field season we investigated disturbed sites of varying age and causes of disturbance, within the Ross Island area. The classification system was developed on previously disturbed sites on Crater

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Hill, Ross Island, Antarctica. Crater Hill provided an excellent case study for pavement rehabilitation studies as it had a chronological succession of disturbed and undisturbed surfaces where the timing of the disturbance is well constrained, from the most recently disturbed wind farm associated bulldozer scrape and cut/fill sites of November 2008, right back to sites disturbed during the inception of Scott Base and McMurdo Station in the late 1950s. Upon examining the sites around Crater Hill and the extent of visible recovery of the desert pavement, it became apparent that a number of observable criteria could be used to distinguish between the relative level of pavement rehabilitation of each surface, and a relative stage of desert pavement recovery could be assigned for each previously disturbed surface.

Morphological features identified as proxies for pavement recovery (Table 1) are outlined below.

Table 1. Provisional Desert Pavement Classification System.

Parameter		Classification Criteria	0 Highly Disturbed	1 Clearly Disturbed	2 Moderately Disturbed	3 Weakly Disturbed	4 Undisturbed
Surface Clasts	**i**	Embeddedness of surface clasts	none	few	some	most	all
	ii	Impressions of removed clasts	sharp/fresh	clear	distinct	faint	not visible
	iii	Degree of clast surface weathering (i.e ventifaction, pitting, polish)	unweathered	weakly weathered	moderately weathered	strongly weathered	very strongly weathered
	iv	% overturned clasts	> 75%	50-75%	20-50%	1-20%	0%
	v	CaCO3 on underside of clasts - "10 cobble" test	0-20%	20-40%	40-60%	60-80%	80-100%
	vi	Degree of development of CaCO3 coatings	not visible	weakly developed	moderately developed	strongly developed	very strongly developed
Pavement	**vii**	Armouring (1m2 test plot)	0-20%	20-40%	40-60%	60-80%	80-100%
	viii	Colour contrast (munsell unit difference)	very strong (>3)	strong (3)	moderate (2)	weak (1)	not visible (0)
Crust	**ix**	Crust integrity (strength/coherence)	structureless	weakly developed	moderately developed	well developed (semi-intact when disturbed)	strongly developed (separates cleanly when disturbed)
	x	Crust thickness	0 mm	<1 mm	1-3 mm	3-5 mm	>5 mm
Surface Stability	**xi**	Evidence of subsidence and melt-out	prominent	distinct	faint	indistinct	not visible
	xii	Accumulation of salt on cut surfaces	abundant	common	some	rare	not visible
	xiii	Patterned ground development	not visible	indistinct	faint	distinct	prominent

Some examples of parameters

Embeddedness – the proportion of the clast below the plane of the ground surface. In areas of mature undisturbed surfaces up to 85% of a cobble-sized clast can be embedded below the ground surface.

Impressions – indentations in the ground surface that result from removal or overturning of clasts during disturbance. Colluvial infilling is time dependant so impressions can persist for a long time in the Antarctic environment.

$CaCO_3$ coatings – carbonate accumulation and salts on the underside of clasts is a measure of pavement maturity and in-situ clasts can be used to determine the relative stage of pavement rehabilitation.

% overturned clasts – precariously ‘perched’ and overturned clasts on the ground surface are an obvious indication of recent disturbance. Unlike mature or rehabilitated surfaces, characterised by a smooth layer of adjacent flat-lying clasts, recently disturbed surfaces contain up-ended overlapping clasts.

Armouring – surface clast density increases with age and stage of rehabilitation; the % of armouring is comparatively lower on recently disturbed surfaces.

Criteria were assigned a severity/extent rating from zero to four, zero being highly disturbed, and four being undisturbed (Table 1). This severity rating system was devised in the field on sites with the timing and nature of the disturbance is well constrained. A relative % recovery for each parameter was then calculated, which is based on the deviation of that parameter – relative to a control or undisturbed equivalent surface. (Table 2). An overall Mean Recovery Index (MRI) could then be assigned to each pavement surface, expressed as pavement rehabilitation stage one through five (Table 3).

Table 2. Relative desert pavement recovery for the McMurdo to Willys Field Pipeline site (Site B), Crater Hill, Ross Island, Antarctica.

Criteria	Site B	Control	% Recovery
i	2	4	50
ii	3	4	75
iii	2	2	100
iv	3	4	75
v	2	4	50
vi	2	4	50
vii	2	4	50
viii	2	4	50
ix	0	1	0
x	0	1	0
xi	2	4	50
xii	2	4	50
xiii	2	2	100
Mean Recovery Index			50

Table 3. Mean Recovery Index (MRI).

MRI (%)	Rehabilitative stage	Description
0	1	newly disturbed
25	2	incipient pavement
50	3	intermediate recovery
75	4	advanced recovery
100	5	indistinguishable from undisturbed site

Provisional results

Case study: Crater Hill, Ross Island, Antarctica

In January 2009 during a detailed investigation of the Crater Hill wind farm site near Scott Base, Ross Island, it was observed that there were distinct differences in the physical integrity of the desert pavement surface at previously disturbed surfaces on Crater Hill, over small distances. Five sites were investigated, four on Crater Hill proper, and one lower on Crater Hill, underneath the fuel pipeline which runs between McMurdo Station and Willys Field. The known dates for disturbance to these individual units ranges from November 2008 to the early 1960s. It was recognised that these observed differences were temporal in origin (as there was little spatial variability in parent material), and inferred that these visible differences reflected various stages in the rate of recovery and desert pavement regeneration post-disturbance. Findings are summarised in Figure 1.

Site A = Recently disturbed turbine site, disturbed Nov 2008.
Clasts not embedded; do not show weathering; >75% overturned. Interlocking pavement armour is absent. Crust undeveloped. Distinct evidence of melt-out/subsidence; accumulation of salt on cut surfaces. Stage of desert pavement recovery: beginnings of the formation of an incipient desert pavement. MRI = 25%.

Site B = McMurdo to Willy Field Pipeline, disturbed c. 1992.
Some clasts are embedded; show some weathering; 1-20% overturned. Some accumulation of salt. Some recovery of patterned ground. Stage of desert pavement recovery: intermediate. MRI = 50%.

Control = Crater Hill far ridge site, undisturbed.
All clasts are embedded; some show weathering; 0% overturned. Very strongly developed $CaCO_3$ coatings. No evidence of melt-out/subsidence. Prominent patterned ground development. Stage of desert pavement recovery: Undisturbed pavement/control. MRI = 100%.

Figure 1. Mosaic of photos shows a panoramic view of Crater Hill study site. Sites A, B, and Control are highlighted.

Conclusion

This two year study revealed that a number of distinguishing morphological features change over time as the pavement re-establishes and stabilises. The parameters used on Ross Island and in the McMurdo Dry Valleys to distinguish between the relative level of pavement rehabilitation, and mean recovery indices were assigned to previously disturbed surfaces to depict their relative stage of desert pavement recovery. Understanding the site-to-site differences in rehabilitative capability is critical when planning activities in the Antarctic environment and will assist managers when dealing with potential impacts of such activities.

References

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