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Site locations and characteristics of miniature patterned ground, eastern Glacier National Park, Montana, U.S.A.

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Abstract: We examined a total of 68 sites with miniature polygonal patterned ground above treeline, along and east of the Continental Divide in Glacier National Park, Montana, USA. Patterned ground develops at three geographic site-types: convex uplands; concave mountain passes and cols; and valleyside slopes. Data were collected at each site to characterize the patterned ground morphometry. Morphometry was similar regardless of site-type, and occurrence was dependent on the presence of fine-grained material on older solifluction terraces or sorted nets.

Key words: patterned ground, solifluction, periglacial, Rocky Mountains, Montana, scale dependence

Introduction and background

Polygonal patterned ground is a widespread phenomenon in both alpine and Arctic environments. Wilson & Clark (1991) reviewed works describing miniature (or small-scale) forms, defined by them as those with a mesh diameter not exceeding approximately 20 cm. Other recent descriptions of miniature patterned ground include those of Wilson (1992, 1995) from the Comeragh Mountains of Ireland and the Falkland Islands, respectively, Pérez (1992) from the Venezuelan Andes, and Wilkerson (1995) from the White Mountains of California, U.S.A.

Miniature patterned ground (mpg) has only rarely been described in the northern Rocky Mountains of Montana, USA, and southern Alberta, Canada. Exceptions include photographs of stone polygons in the Beartooth Mountains of southern Montana (Gleason *et al.*, 1986; Krantz, 1990) and more detailed data from the Mount Rae area of southern Alberta (Gardner *et al.*, 1983; Smith, 1986). We previously provided a brief description of mpg from a location in northwestern Montana near the Canadian border (Butler & Malanson, 1989). During several subsequent summers of fieldwork above treeline in Glacier National Park, Montana, we have encountered dozens of additional sites where mpg is well developed. Because of the relative paucity of morphometric data on mpg in the northern Rockies, we present such data here from those sites.

The study area

We carried out this study in eastern Glacier National Park (GNP), Montana, USA, which lies in the leeward rainshadow of the Continental Divide (Fig. 1). The distribution of alpine tundra and upper treeline in GNP is a complex pattern resulting from interactions of wind-redistributed snow, soil moisture conditions, slope steepness, aspect and exposure, and catastrophic slope processes (Walsh *et al.*, 1992; Butler & Walsh, 1994; Butler *et al.*, 1994; Malanson & Butler, 1994; Walsh *et al.*, 1994). The elevation of alpine tundra is therefore variable, but is typically encountered above ca. 2,000 m. Butler and Malanson (1989) reviewed the sparse literature on patterned ground from the Park, and described relict turf-banked terraces and stone nets attributed to an earlier Neoglacial climatic deterioration.

Fig. 1. Patterned ground sites in eastern Glacier National Park, Montana, U.S.A., examined in this study.
a – 4 sites, Natahki cirque area; b – 15 sites, Cataract Creek to Siyeh Pass area; c – 15 sites, East Flattop Mountain and Napi Point; d – 1 site, Hidden Pass area; e – 18 sites, Scenic Point/ Bison Mountain area; f – 5 sites, Dawson Pass area; g – 10 sites, Firebrand Pass area.

Methodology

In a related study (Butler *et al.*, 1994) we examined the question of treeline stability at 25 locations in eastern GNP. At a total of 68 sites in the adjacent alpine tundra above those treeline sites, we encountered miniature stone nets and polygons similar to those briefly described in our 1989 paper. The 68 sites were found in three general geographic settings: convex uplands, concave passes and cols, and valleyside slopes. For each of these 68 sites, we employed the following methods:

– the diameter of the fine-grained centers of each polygon was recorded;

– a visual estimate of the percent surface area comprised of fines (defined here as the finer-grained, < 2 cm, materials comprising polygon centers) was made at each site;

– the long axis of the 10 largest clasts present at each site was measured;

– the local geomorphic setting at each site was described and subsequently categorized into the three geographic site-types;

– the site elevation was extracted from U.S. Geological Survey 1:24,000-scale topographic maps (contour interval = 40 feet);

– the mpg was photographed from a height of approximately 1.5 m. A 49-mm lens cap or measuring tape was included in the approximate center of all photographs for scale purposes. Measurements on panchromatic photographic prints of each site were made, from the center of each polygon to the center of its nearest neighbor and recorded to the nearest 5 mm. Only complete polygons, and those whose nearest neighbors were completely visible on each photograph, were included in the nearest neighbor measurements. Surface area of each site was calculated from the rectangular photographic images, but areas of boulders or vegetation covering large areas were excluded. Using these data, we calculated the Nearest Neighbor statistic, or **R** value, using the feature-center method (Vitek, 1973, 1978);

– descriptive statistics were calculated for each variable (**R** value, percent of fine-grained clasts (%Fines), large clast mean (Clast), diameter, and elevation), for the 68 total sample sites, and also calculated for each of the three site-type subsets (Table 1);

– simple correlations were generated for the relations between the variables, for the entire sample of 68 sites, and by site-type (significant correlations are shown in Table 2). **R** values were regressed on % fines and large clast mean using stepwise multiple regression for both the entire data set and the site-type subsets, to assess possible microclimatic controls on polygonal pattern associated with moisture retention capability (higher percentages of fines and smaller sizes

Fig. 2. Typical convex upland site, Scenic Point area. Patterned ground developed on the treads of the relict solifluction terraces.

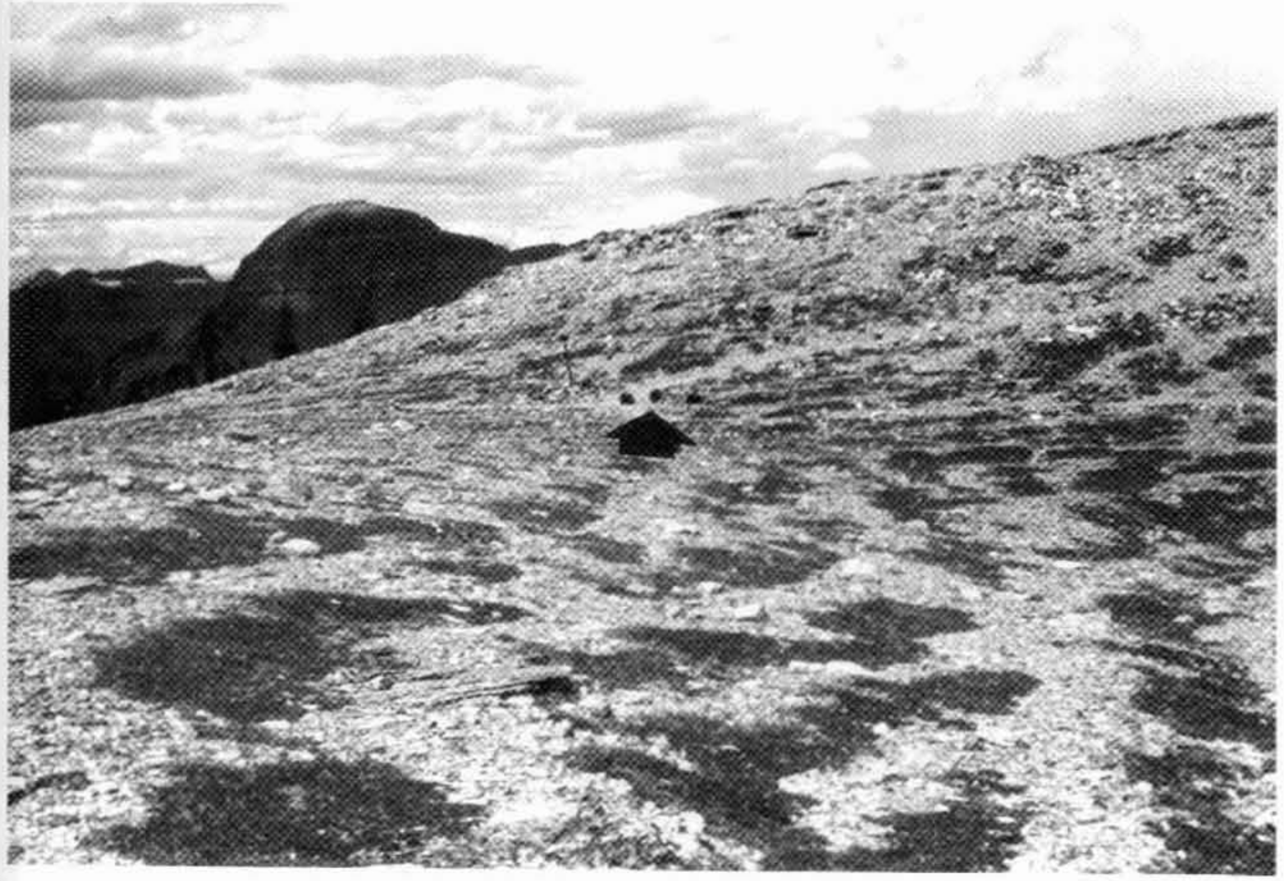

Fig. 3. Typical concave pass site, Dawson Pass. Arrow points to a group of 3 daypacks, for scale. Patterned ground developed on relict solifluction treads.

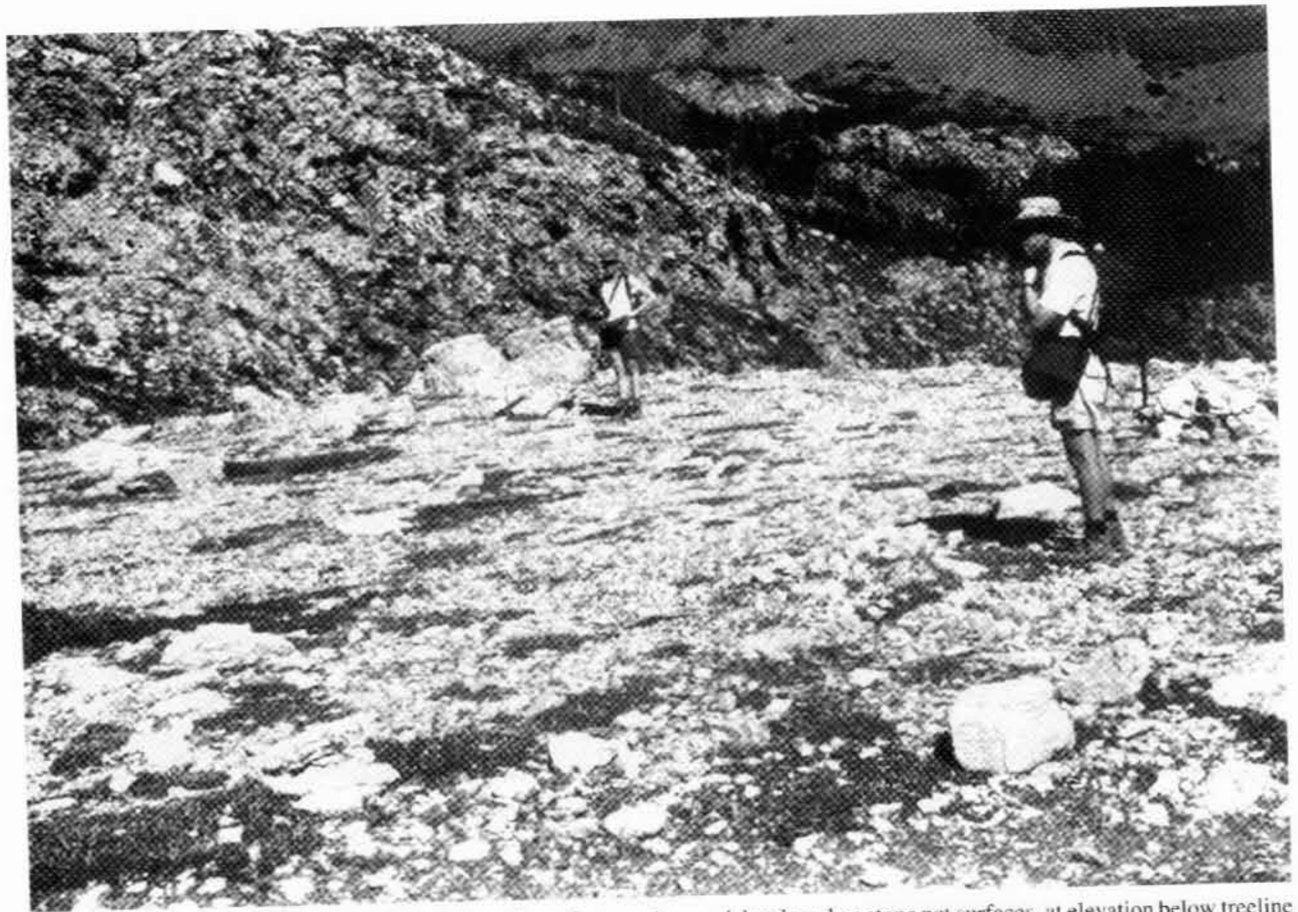

Fig. 4. Low-angle valleyside site, Firebrand cirque floor. Patterned ground developed on stone net surfaces, at elevation below treeline (note subalpine forest in background).

Fig. 5. Sorted nets pattern prevails on the steeper slope in center mid-distance, with solifluction terraces on the gentler slopes both above and below the nets.

Table 1. Descriptive statistics (means), patterned ground sites*

Sample Group	R Value	Centroid Diameter	Clast	%Fines	Elevation
Entire 68 Sites	0.93 S.D. #: (0.20)	5.5 cm	11.3 cm	18%	2,219 m
Convex Upland Sites (N=34)	1.01 S.D.: (0.20)	5.8 cm	11.5 cm	19%	2,174 m
Concave Pass Sites (N=15)	0.91 S.D.: (0.22)	5.6 cm	11.3 cm	17%	2,263 m
Valleyside Sites (N=19)	0.80 S.D.: (0.13)	5.2 cm	10.9 cm	17%	2,266 m

* Variables are as defined in the text.
# Standard deviation values of **R** statistic in parentheses.

of surrounding clasts should allow for greater moisture retention, leading to more efficient frost action and subsequent pattern development). Elevation and Centroid Diameter were omitted from this procedure because of the absence of significant relationships between those variables and **R** values (Table 2).

Table 2. Significant (0.05-level) simple correlations between sampled variables

R Value	%Fines	Clast	Elevation	Centroid Diameter
Total 68 Sites	n.s.	n.s.	n.s.	n.s.
Convex Upland Sites	n.s.	-0.1882	n.s.	n.s.
Pass Sites	n.s.	0.6014	n.s.	n.s.
Valleyside Sites	0.4618	n.s.	n.s.	n.s.

Results

Site-types. Miniature polygonal patterns have developed in three distinct topographic settings. The gently sloping convex upland site-type (Fig. 2) is the most widespread of the three site-types in eastern GNP, occupying a general elevational range of 2,150–2,300 m (Table 1). These locations are typically windswept and very exposed to solar radiation. We collected data at 34 such locations.

Concave mountain pass site-types (Fig. 3) occur in cols along and east of the Continental Divide, at elevations ranging from ca. 2,200 to > 2,470 m (Table 1). The major characteristic at these sites (our sample size = 15) is extreme windiness, as winds funnel through the breaches in the glacial aretes.

Valleyside slopes are the most shaded of the three site-types. They occur at a variety of elevations (our sample = 19 sites), either where alpine tundra is locally depressed below the treeline/tundra ecotone, or high on cirque valleysides. The presence of early 20th-century wildfires in one cirque (Fig. 4) may have contributed to patterned ground development there by removing forest cover and thus increasing the site's exposure and vulnerability to frost action at an elevation well below local treeline.

Geomorphic setting. Approximately 80% of our sample sites were located on the treads of inactive solifluction terraces resulting from an earlier climatic deterioration (Figs. 2, 3) (Butler & Malanson, 1989), and the remaining sites occurred within the polygonal centers of relict stone nets on steeper slopes (Fig. 5) attributable to the same earlier period. The mpg of every concave mountain pass site was located on solifluction treads. Most convex upland sites were associated with solifluction treads, but were also located within relict stone nets on the crest of East Flattop Mountain. Fifteen of our nineteen valleyside sites also were located on relict solifluction treads, the four exceptions occurring within relict stone nets in one windy cirque.

Regardless of whether the mpg sites were located on the surface of solifluction treads or within centers of stone nets, the mpg are scale dependent (*sensu* Walsh *et al.*, 1998), i.e., their presence is dependent on the presence of the larger, relict landforms. Without the concentration of fine-grained soils on the surface of the solifluction treads (Butler & Malanson, 1989) or within stone nets, the present-day mpg would not have formed. This conclusion is corroborated by the absence of mpg at many similar elevations and aspects where coarse talus and other colluvial deposits offer insufficient fines for the development of the mpg.

Morphometric data. Table 1 presents the descriptive statistics for the data set and the site-type subsets. Values for the nearest neighbor **R** statistic ranged from a low of 0.49 to a high of 1.41. Mean **R** values of the three site-types were not significantly different, nor were any of the other variables. The general pattern, size of centroids, percentage of fines, and size of large clasts was similar across geographic site-types.

No combination of the independent variables explained any statistically significant percentage of the variation in **R** value for the total data set, nor for the convex upland sites subset. For the concave pass sites subset, Clast explained low but statistically significant amounts of variation in the **R** value, and %Fines explained low but statistically significant variations in **R** value of the valleyside sites subset. The equations for these relationships are:

R value = 0.059906 + 0.0075229 (Clast);
(adjusted $r^2 = .31$; $p < .01$)

and

R value = 0.65931 + 0.0086451 (%Fines);
(adjusted $r^2 = .17$; $p < 0.03$).

Discussion and conclusion

The morphometry of miniature patterned ground in eastern GNP is not site specific. Similar patterns occur regardless of location on wind-swept passes, valleyside slopes, or convex uplands. The process of frost sorting must be sufficiently uniform and intense to override any local site conditions that could induce variations in morphometry.

The geographic locations of miniature patterned ground are dependent on the past locations of larger forms of patterned ground from early climatic deteriorations during the Holocene. Without the presence of fine-grained soils on the treads of older solifluction terraces or within the centers of older patterned nets, miniature patterned ground would not currently exist in spite of the efficacy of frost processes in the area.

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