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Laboratory-produced sorted patterned ground by repeated frost heaving

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Sorted patterned ground is ubiquitous where gravelly fine soils experience freeze-thaw cycles, but laboratory models have rarely been successful in reproducing such patterns. Here we report the first result of an attempt to reproduce miniature sorted patterns by repeating needle-ice formation, which simulates frost sorting in regions dominated by diurnal freeze-thaw cycles. The laboratory models (50×50×35 cm) consist of near-saturated volcanic fine soil topped by small stones with varying sizes, SSG (∼8 mm), SG (∼16 mm), MG (∼19 mm) and LG (∼26.5 mm), and varying surface coverage (20, 40 and 60%). The stones were white-painted and placed in a grid on the surface. These models were subjected to 10–20 temperature excursions between 10°C and −5°C in 12 hours. The evolution of surface patterns were visually traced by vertical and oblique photogrammetry taken at intervals of 10 minutes. The time series of pictures were compiled to produce animations. In addition, a data logging system continuously monitored vertical soil displacements, soil temperatures and moistures at different depths.

All experimental runs displayed needle ice formation (2–3 cm in height) and resulting displacement of stones. Differential frost heave took place between the soil domains and stones, such that the soils tend to heave faster and higher than the stones. The preferential and higher heaving led to outward movements of the soil domains after cycles of frost heave and thaw settlement, and subsequently to concentration of the stones. In plan view, smaller stones (SSG and SG) showed relatively fast (1–2 mm/cycle) and long-lasting (up to 20 cycles) movements. In contrast, larger stones (MG and LG) displaced rapidly (1–2 mm/cycle) in the first 5 cycles, but thereafter they were stabilized. The lowest stone coverage (20%) produced stone islands at horizontal intervals of about 12 cm, whereas higher coverage (40%) resulted in a stone circle-island complex with a mean diameter of 13 cm. The latter geometry appears to represent incipient sorted circles, dimensions of which are comparable to those observed in the field. The experiments imply that needle-ice activity induces frost sorting rapidly, which potentially allows the formation of stone islands and incipient sorted circles within one or a few years, but more regular circles may need hundreds of diurnal frost heave cycles (i.e. decade-to-century time scales).