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The enigma of large sorted stone stripes in the tropical Ethiopian Highlands

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The Bale Mountains in the southern Ethiopian Highlands (7-8°N) are formed of multiple superimposed flood basalts and comprise Africa's largest plateau above 4000 m. Glacial and periglacial landforms are well-preserved and facilitate the reconstruction of the paleoclimate and landscape of the afro-alpine environment. During the Late Pleistocene, an ice cap covered the central part of the plateau and outlet glaciers extended down into the northern valleys. A striking geomorphological feature on the plateau are large sorted stone stripes that consist of hardly-weathered columnar basalt and are up to 2 m deep, 15 m wide and 200 m long. The stone stripes are located between 3850 and 4050 m at gentle slopes (4-8°) of two volcanic plugs 3-5 km south of the highest peak (Tullu Dimtu, 4377 m) and in the far west of the plateau. Sorted patterned grounds of similar size are characteristic for periglacial environments of the high latitudes, but unique for tropical mountains since their formation requires permafrost and a deep active layer. While diurnal freeze-thaw cycles in tropical mountains are sufficient for the genesis of small-scale patterned grounds, the sorting of large basalt columns (length >2 m, diameter >40 cm) assumes seasonal (or multi-annual) freeze-thaw cycles and a deep active layer. When and under which climatic conditions the sorted stone stripes in the Bale Mountains formed, remains an unsolved mystery. The stone stripes might have developed during the Late Pleistocene under periglacial conditions in close proximity to the ice cap or after deglaciation (~15-14 ka). To assess the timing of the final stagnation of the stone stripes, we determined the age of six basalt columns from two different stripes using ³⁶Cl surface exposure dating. In addition, we installed temperature data logger in 2, 10 and 50 cm depth across the plateau and between the stone stripes to investigate the present thermal conditions and diurnal and seasonal temperature variations in the ground. The difference between the measured mean annual temperature and presumed average ground temperature for permafrost ($\leq 0^\circ\text{C}$) indicates an extreme temperature depression on the plateau of $\geq 10^\circ\text{C}$ during the formation period of the sorted stone stripes. Such a Late Pleistocene cooling would be unprecedented in the tropical mountains. Finally, we applied a simple statistical model forced with meteorological data from a nearby weather station to simulate ground temperatures and test which climatic preconditions are necessary for the formation of sporadic permafrost in the Bale Mountains.