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Structural and erosive Effects of Lightning on Sandstone: An Experimental Investigation

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Recent prognoses predict an average temperature increase of the world's climate of about 1.5 to 2 °C until the end of 21st century. This change leads not only to a rise of the sea level but also to an increase of thunderstorms and therefore to a ~25 percent increase of cloud-to-ground lightning events (Romps et al., 2014). It is known that (i) lightning strikes are able to fragment surface rocks, which probably influences the erosion rates at exposed mountain areas (Knight and Grab, 2014), and (ii) the efficiency of the process increases due to the predicted climate change. However, our knowledge about the electro-mechanical destruction of rocks caused by high energetic lightning is incomplete. In this study, laboratory experiments of lightning strikes were performed in order to understand the fragmentation of rocks and changes to landforms by lightning. The artificial lightning with known electric current was simulated by a high-current generator in the laboratories of the Fraunhofer Ernst-Mach Institute for High-Speed Dynamics (Freiburg, Germany). Different currents were transferred over a distance of ~2mm onto water-saturated sandstones by using a copper cathode (3 experiments; U, I, E, Δt: 6 kV, 200 kA, 0.1 MJ, 0.7 ms; 9 kV, 300 kA, 0.19 MJ, 0.9 ms; 12 kV, 400 kA, 0.35 MJ, 0.5 ms). The damaged sandstones were investigated by means of optical and electron-optical methods as well as by X-ray computed tomography to determine the modes and dimensions of melting and fragmentation. Digital elevation models of craters formed by ejection were obtained by white-light interferometry. The lightning experiments produced small craters (~1 cm in diameter, ~0.5 cm depth) which surfaces and sub-surfaces consist of silicate melts (molten quartz and phyllosilicates). The silicate melts reach several hundred micrometers into the sub-surface and resemble the appearance of natural fulgurites. Melting of quartz indicate temperatures of at least 1650 °C. In addition, the occurrence of macroscopic and microscopic fractures was observed. Large fractures, which are several millimeters in length, propagate radial-symmetrically from the impact point into the sandstone. The extent and depth of the produced lighting craters, the amount of melt and the amount of fractures increases with increasing energy of the artificial lightning strike. The experiments show that the largest fraction of the input energy is invested in heating and melt formation, and secondary in fragmentation. The melt and crater volumes are considered representative for the erosive power of this physical process. Based on our investigations, the global lightning strikes' density and the assumption that around 1-10 MJ of natural lightning strikes are delivered to the strike point, a maximum erosion rate of lightning of about ~1.8 μm/yr could be calculated. This result indicates that cloud-to-ground lightning play a non-negligible role in the global erosion system.

References:

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