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Massively dilatant faults in Iceland: Surface geometries derived from high-resolution UAV data

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Normal faults in basalts can develop massive dilatancy close to the Earth's surface, forming major fluid pathways. These massively dilatant faults (MDF) are omnipresent in Iceland or the East African Rift. Despite their importance for e.g. geohazard assessment or geothermal energy, their detailed geometry at surface and depth is not well understood. We contribute to this understanding by analyzing their surface geometries using unmanned aerial vehicles (UAV), providing a much higher resolution than aerial/satellite imagery and a broader overview than ground-based fieldwork.

Our study areas on Iceland offer excellent outcrops of MDF, dominantly formed in successive lava flows and different kinematic settings along the exposed Mid Ocean Ridge. We applied UAVs to capture sets of several hundred overlapping photographs of MDF, which we process in photogrammetry software to create 3D point clouds, high resolution (5 – 15 cm/pixel) digital elevation models and orthorectified images. The resulting dataset consists of more than 20 km (along strike) of faults and fractures and enables us to map the fault traces in the scale of single basalt columns, allowing measurements of length, heave and throw and high-resolution morphological analyses such as the calculation of slope angles and surface ruggedness.

Based on the relationships of heave vs throw, we suggest a number of end member types of fault structures including dilatant faults with significant heave and throw, dilatant faults dominated by tilted blocks (TB), throw dominated non-dilatant normal faults and heave dominated mode I fissures. Furthermore, we infer that these fissures can develop a heave up to 10 m without developing a significant amount of throw. Vice versa, steeply dipping normal faults may accumulate 10 – 15 m of throw without developing a significant heave. The general trend of heave and throw strongly fluctuates around a 1:1 aspect ratio, while TB dominated normal faults tend to have a larger heave with respect to their throw, caused by i) an overestimation of the heave due to the TB, as the hanging wall segment rotates away from the footwall and ii) an underestimation of throw in case of measurements performed on the area influenced by the TB. Undulations are more prominent in measurements of the heave, caused by the segmentation of the fault or collapsed relays leading to a local increase in measured heave, while variations in throw develop over larger distances and are less influenced by local changes of the surface expression of the fault.