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The surface structures of massively dilatant faults in Iceland and their implications on subsurface geometries

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Massively dilatant faults (MDF) are ubiquitous structures at rift zones worldwide. They act as fluid pathways up to great depth, making them interesting for applications such as geothermal energy, groundwater or hydrocarbon exploration. While estimates were given in the past for the depth of open fractures based on basalt strength, the actual 3D geometry of these faults at depth is still unknown. Especially the transition zone between opening mode fractures at the surface and shear faults at depth is enigmatic. Is it a single sharp kink, or a thick complex zone of mixed opening and shear mode patches? Existing publications on hybrid failure suggest the latter; however, the presence of vertical cooling joints throughout the basalt layers would make a sharp kink possible as well. Since we cannot see down to several hundred meters depth, can we understand the subsurface structures from surface observations?

We chose to study MDF in Iceland as there we find exceptional outcrops of rift zone faults in purely extensional and oblique fault settings. We show observations of structural features that are so far unnoticed in literature and discuss their implications on subsurface fault structure. Open cavities form along massively dilatant faults and we were able to verify depths of more than 20 m in many places and up to 40 m in the Vorgar fissure swarm (SW Iceland). Within these open fractures, basalt columns tend to fall off and jam between the fracture surfaces. Sediment input and soil development causes the formation of stockworks building closed floors. Hanging and collapsed relay ramps can enhance this process.

Mechanical stratigraphy has a big influence on the structure of dilatant faults at depth as weaker layers prohibit the formation of opening mode fractures. Lateral mechanical variations caused by the mostly vertical to subvertical cooling joints further influence fault geometry not only at the surface but also at depth. We observe fractures and faults filled with sand, rubble and lava. Especially the latter, subsequent filling or covering of open fractures by lava and following faulting, will affect fault geometry at depth. Depending on lava viscosity and fracture aperture, these volcanic growth faults can form large open caves due to the subsequent opening and covering of fractures, or lava can fill up existing open fractures. Tilted blocks at the fault scarp cannot only obscure the true amount of opening, but also the location of opening mode fault in the subsurface.