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Structure of active and extinct geothermal systems in Iceland

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The active volcanic zones of Iceland are characterised by a high heat flow and extensive geothermal activity. The high-temperature geothermal systems are mainly confined to volcanic systems and especially central volcanoes and seem to be subject to a strong structural control. We compared structural data on geothermal fields in the active Hengill Volcanic System in the West Volcanic Zone in Southwest Iceland with the deeply eroded palaeo-geothermal field of the Tertiary Geitafell Volcano in Southeast Iceland.

The Holocene Hengill Volcano is the site of one of the most powerful geothermal fields in Iceland and seismically very active. Structurally, it is dominated by large NNE-striking normal faults. Detailed field studies of several thousand fractures in the area were carried out including the measurements of the attitude, opening, and displacement of some 2000 joints, about 1000 mineral veins, and 29 large normal faults. In addition, careful quantitative studies of fractures from aerial photographs were made, focusing on the orientation of the large normal faults and other lineaments.

The average strike of the 29 normal faults measured in the field, as well the 251 normal faults measured on aerial photographs, is 032˚. Most of the faults dip steeply. The eastern shoulder is dissected almost entirely by NW-dipping normal faults. There are nearly twice as many normal faults dissecting the western shoulder; half of those are NW-dipping, (as on the eastern shoulder), the other half being SE-dipping. Also, the average throw is about 31 m for the normal faults dissecting the eastern shoulder, but 43 m for the faults dissecting the western shoulder. By contrast, the average trace length of normal faults dissecting the eastern shoulder is about 0.75 km but for the western shoulder 0.55 km. We observed a clear link between the location of geothermal springs and normal faults at the surface. This connection is currently used in the drillings for the geothermal power plants of Nesjavellir and Hellisheidi located north and southwest of the Hengill Volcano.

For comparison, we analysed the fossil geothermal system of the Geitafell Volcano, an extinct Tertiary central volcano that has been eroded down to its core. This allows us to study the associated geothermal system directly adjacent to the heat source of the volcano represented by gabbro bodies that were once part of the shallow magma chamber of the Geitafell Volcano. We studied the fracture network inside the gabbro to characterise the fluid flow in the heat source itself and therefore measured the attitude and thickness of 408 mineral veins and 1087 joints. The results indicate that there are two major (NE-SW and NW-SE) and one minor set of mineral veins (NNE-SSW). This fits very well with the attitude of the joints indicating that mineralising geothermal fluids used cooling joints as pathways through the gabbro. In the top region of the gabbro, the density of mineral veins is high compared with the density of joints suggesting that many columnar joints were sealed by mineralising hydrothermal fluids during the high-temperature geothermal activity of the Geitafell Volcano. Additionally, the attitude of 68 hydrothermal breccia zones was measured in the sheet swarm surrounding the magma chamber. Hydrothermal breccia zones are formed by high-energy movement of geothermal fluids. The pathways of the geothermal fluids are fractures and are therefore strongly influenced by the fracture pattern in the volcano in which they occur. There are two main strike directions: NW-SE and ENE-WSW.

A comparison of the results of our studies in the Hengill and the Geitafell Volcano shows that geothermal systems associated with central volcanoes at the surface and at depth are fracture-controlled and thus strongly dependent on the local stress field in and around the volcano.