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Characterization and imaging of a near-vertical hydrothermal fault zone embedded in crystalline rocks based on hydrophone VSP data

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A shallow, hydrothermally active, near-vertical fault zone embedded in fractured and sheared crystalline rocks of the Central Swiss Alps has been drilled and geophysically explored in view of its potential analogies to planned petrothermal reservoirs in the Alpine Foreland.

Vertical seismic profiling (VSP) experiments using a 24-channel borehole hydrophone array with sensors every 1 m have been performed to image the fault core and to detect hydraulically open fractures. The spatially dense sampling of the wavefields allows for isolating borehole guided modes (tube-waves), which in turn enables the production of a reflected tube-wave stack as well as pseudo-standard VSP profiles.

Walk-away hydrophone VSP data were acquired with a crooked-line survey geometry and processed with 3D methods. Hereby, a laterally changing velocity cube, which is representative of the vertical structure variations along the strike of the fault, is generated and utilized for Kirchhoff pre-stack-depth-migration imaging. The resulting seismic image has been successful in delineating various vertical structures, notably the target fault zone, as well as a sub-horizontal fault that cuts the target zone. Moreover, hydraulically open fractures and fracture zones can be clearly identified and localized by the generated tube-wave stack.

The interpretation of the VSP data is complemented and corroborated through a comprehensive suite of geophysical borehole logs, which characterize the petrophysical variations in response to ductile and brittle deformation in the fault core and the surrounding damage zones.

This study exemplifies typical targets of hardrock seismic exploration, where the structures are commonly near-vertical, discontinuous, and of relatively low acoustic impedance contrast and thus illustrates the benefits of using borehole seismic methods in such environments, particularly for targeting shear zones for petrothermal reservoirs or hydrothermal mineral deposits.