

## P 7.5

# Fault orientations inferred from analysis of a microseismic cluster dataset of the Basel EGS reservoir agree well with borehole fracture data

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Electricity production from petrothermal systems requires the circulation of fluids through rock masses that are sufficiently hot and thus, in areas with normal geothermal gradient like the Swiss foreland, involves drilling to depths often ranging between about 4 and 5 km below ground (e.g., Kohl et al., 2005). As a consequence, characterisation of the reservoir rock mass is often limited to observations and tests made in a small number of boreholes, sometimes in a single well like in the *Deep Heat Mining* project in Basel, Switzerland. Rock mass characterisation along the 5 km deep Basel-1 well included temperature profile, identification of permeable structures, state of stress and rock mechanical properties, lithology, and occurrence and properties of natural fractures (e.g., Ziegler et al., 2015). In order to build a structural model that can be used as input for numerical models aimed at predicting reservoir injection and production behaviour, knowledge of permeable fractures (e.g., brittle faults) that populate the reservoir away from the well is essential. Such information can partially be inferred from microseismic data obtained during stimulation operations. Previous studies by Asanuma et al. (2007), Dyer et al. (2010), Deichmann et al. (2014), and Kraft and Deichmann (2014), among others, investigated the waveform similarity of seismic events. Events with high seismic waveform similarity were grouped into clusters and interpreted to have originated from slip of patches of a common fault or fault zone. Improved techniques to pick P- and S-wave arrival times and master-event relocation led to substantial reduction of the relative location errors of the events in a cluster.

In this study we investigated the orientations of faults, inferred from the microseismic cluster dataset from Kraft and Deichmann (2014). This dataset includes 370 small clusters that have a median extent in x, y, and z directions of about 7 m, 9 m, and 12 m, and depth greater than 3.6 km bgs. We used principal component analyses to extract fault orientations for each cluster under the assumption that the events in a cluster have occurred on a single planar fault patch of negligible width. The uncertainty in the fault orientation estimates was assessed using Monte-Carlo-type simulations where the locations of the events within each cluster were varied within their individual location error ellipsoids. We then compared the orientations of inferred *well-constrained* faults (14 faults with orientation uncertainty characterised by one standard deviation (SD) <15°) and *moderately constrained* faults (36 faults; 15° < SD < 22.5°) with borehole fracture data. Our analysis shows considerable agreement in the strike directions (NNW to NW) of microseismically inferred faults (Figure 1a) and zones of high fracture frequency previously identified from image logs run in the Basel-1 well (Figure 1b). Some discrepancies were also evident: fault planes from seismic event clusters cover a very narrow range of orientations and are essentially vertical, with a slight tendency towards NE dipping; in contrast, fracture zones from fracture analyses at the well show a much larger orientation dispersion and have more SW dipping structures. However, only a small number of clusters (14%) yielded relatively robust fault orientations, most likely because the events in the clusters were not sufficiently widely dispersed. Thus, many failure planes activated within the reservoir were not identified in the analysis, either because the orientation of the fault patch could not be usefully constrained, or because the events were not a member of a cluster. Planes that slip aseismically will also remain undetected. These limitations will lead to a biased reservoir structural model. Thus, we are currently working on microseismic clusters of larger sizes (e.g., identified by Dyer et al., 2010) and on integration of the various Basel microseismic imaging datasets.

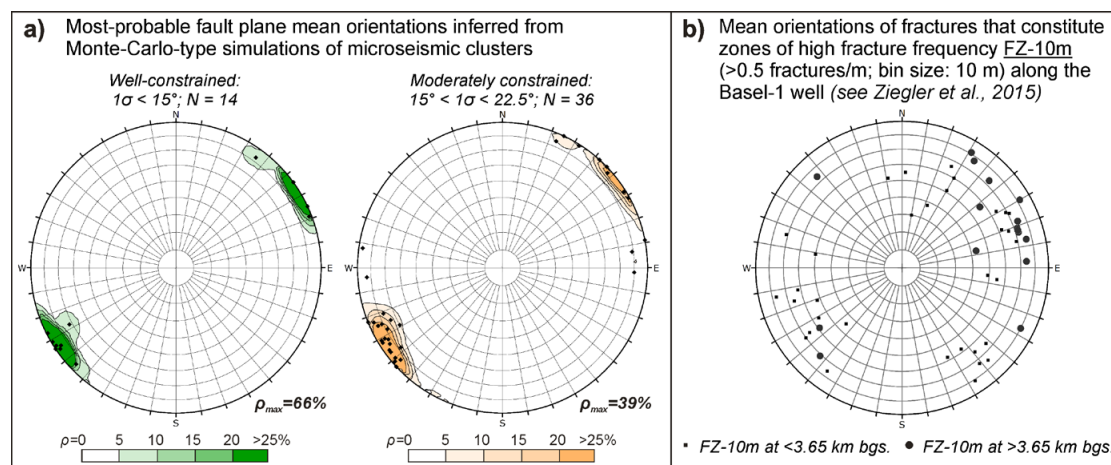


Figure 1. Comparison of a) poles to fault planes identified from microseismic clusters, with b) poles of fracture sets that constitute assumed planar fracture zones identified along the Basel-1 well. Note that the subvertical trajectory of the Basel-1 borehole leads to a bias in intersecting subvertical fractures, i.e., these are underrepresented in b). Lower hemisphere, equal area projections.

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## P 7.6

### Enhancement of permeability in geothermal reservoirs: the example of the Salanfe lake – Val d'Illiez geothermal area

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Extraction of deep groundwater for accessing geothermal heat is an innovative method in the field of renewable energies. In engineered geothermal systems (EGS), targeting depths >3 km, the circulation and extraction of water is promoted by means of a doublets of wells and a stimulated reservoir. In geothermal projects of medium temperature, natural groundwater is extracted from deep aquifer systems located at depths from 1 to 3 km. Both cases are often characterized by a very low permeability of the reservoir, which limits the capacity to produce cost-efficient flow rates. This is principally because of mechanical, i.e. increasing stress with depth, and chemical, i.e. clogging of fractures by mineral filling, processes. Thus, reservoir stimulation by means of hydraulic shearing events is a critical method for the geothermics industry. To ensure permanent fracture permeability, hydraulic shearing aims to activate in shear natural pre-existing fractures favorably oriented, i.e. having an angle ranging between 15–45° with the maximum principal stress  $\sigma_1$ , by means of injecting a fluid pressure lower than the minimum principal stress  $\sigma_3$ . However, it is still unclear (i) how much the reservoir permeability is enhanced during hydroshear slip events and (ii) what is the resulting reservoir geometry.