The SpannEnD project

Prediction of the recent crustal stress field of Germany

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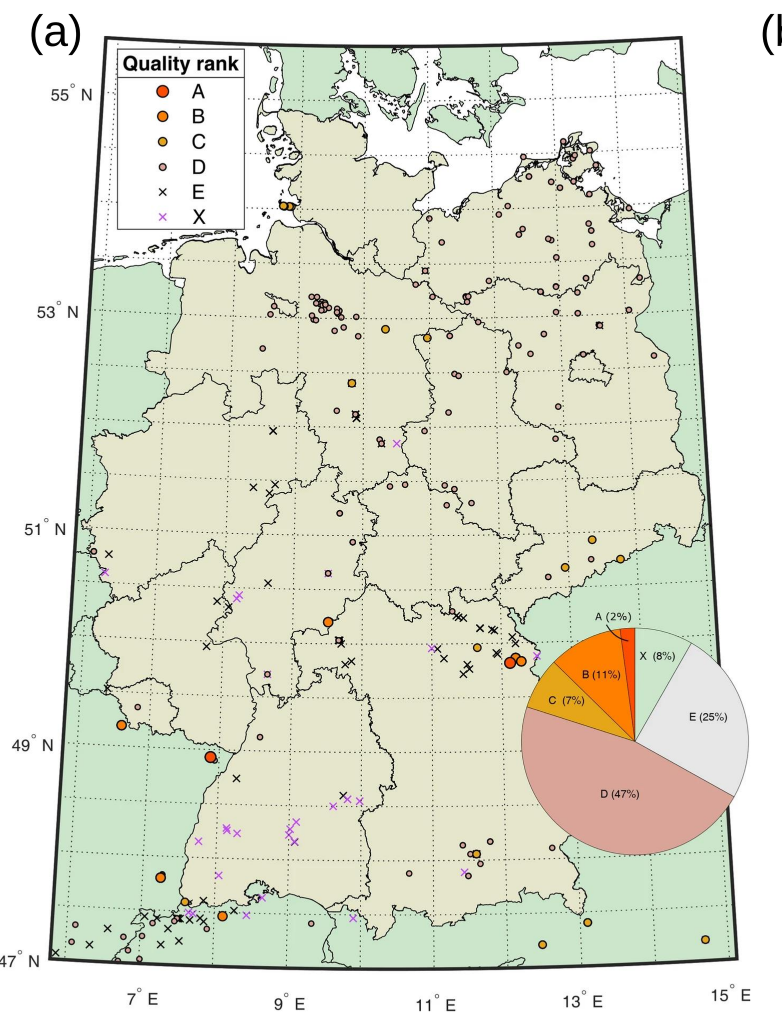
The SpannEnD project

SpannEnD is an acronym for "**Spann**ungsmodell **En**dlagerung **D**eutschland". It is a collaborative research project of three German research institutions (TU Darmstadt, Karlsruher Institut für Technologie & Deutsches Geoforschungszentrum Potsdam), funded by the Federal Ministry for Economic Affairs and Energy. The SpanEnD project aims to improve the knowledge of the recent crustal stress state of Germany by data compilation and geomechanical-numerical modeling. Collected stress data records are quality ranked and published in the first stress magnitude database for Germany (Morawietz & Reiter, 2020). A short overview of the data records is shown in Figure 1. These pointwise data records are used as calibration data for a geomechanical-numerical 3D model of Germany which enables for the first time a continuous prediction of the complete 3-D stress tensor (Ahlers et al., 2021a, b).



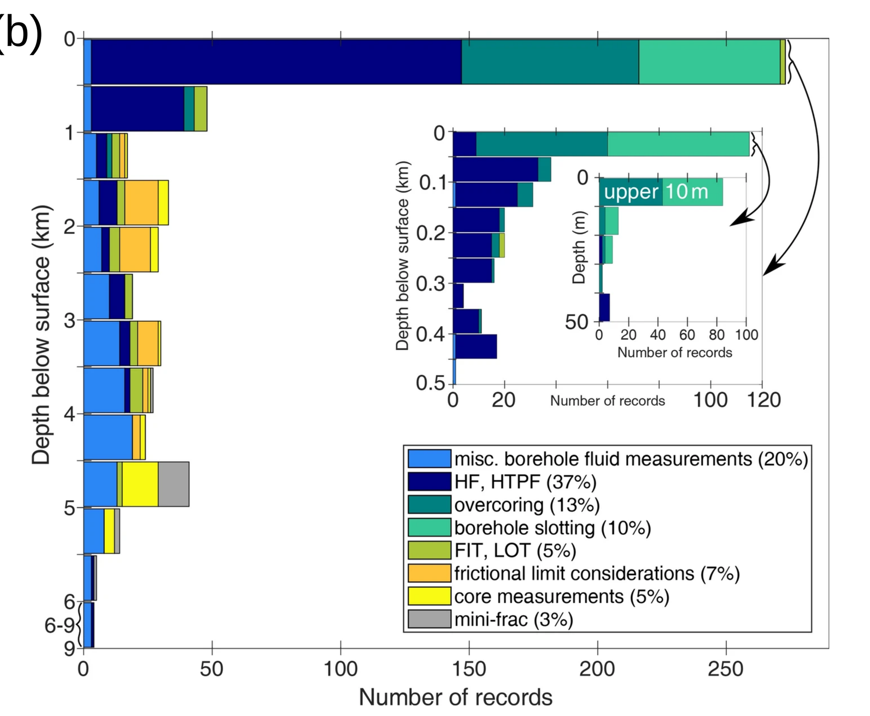


Figure 1: Overview of the open-access stress magnitude database for Germany. a) Map of quality rated data records b) Depth distribution and measurement methods. (Morawietz et al. 2020)

Geomechanical-numerical model

The extend of the geomechanical-numerical 3D model has been chosen with regard to important geological structures and the orientations of the maximum horizontal stress (S_{Hmax}) derived from the World Stress Map (WSM). It covers an area of 1000 x 1250 km^2 (Figures 2) and reaches up to 100 km depth. The model contains 22 units: 16 sedimentary units, four upper crust units, the lower crust and parts of the lithospheric mantle. The sedimentary units are only resolved in the central part and main area of interest (Figure 2). Each unit is parametrized with individual material properties (density, Poisson's ratio and Young's modulus). The resolution of the model is laterally 2.5 km and vertically - within the upper 10 km - 240 m. Below 10 km depth the resolution decreases. Overall, the model contains about 11 million hexahedral elements. We assume linear elasticity and the FE method is used to solve the equilibrium of forces. Displacement boundary conditions are defined perpendicular to the vertical model edges (Figure 2). Then the displacements are varied until a best-fit with the calibration data is achieved. As calibration data magnitudes of the minimum and maximum horizontal stress (S_{hmin} & S_{Hmax}) from the magnitude database of Morawietz & Reiter (2020) are used.

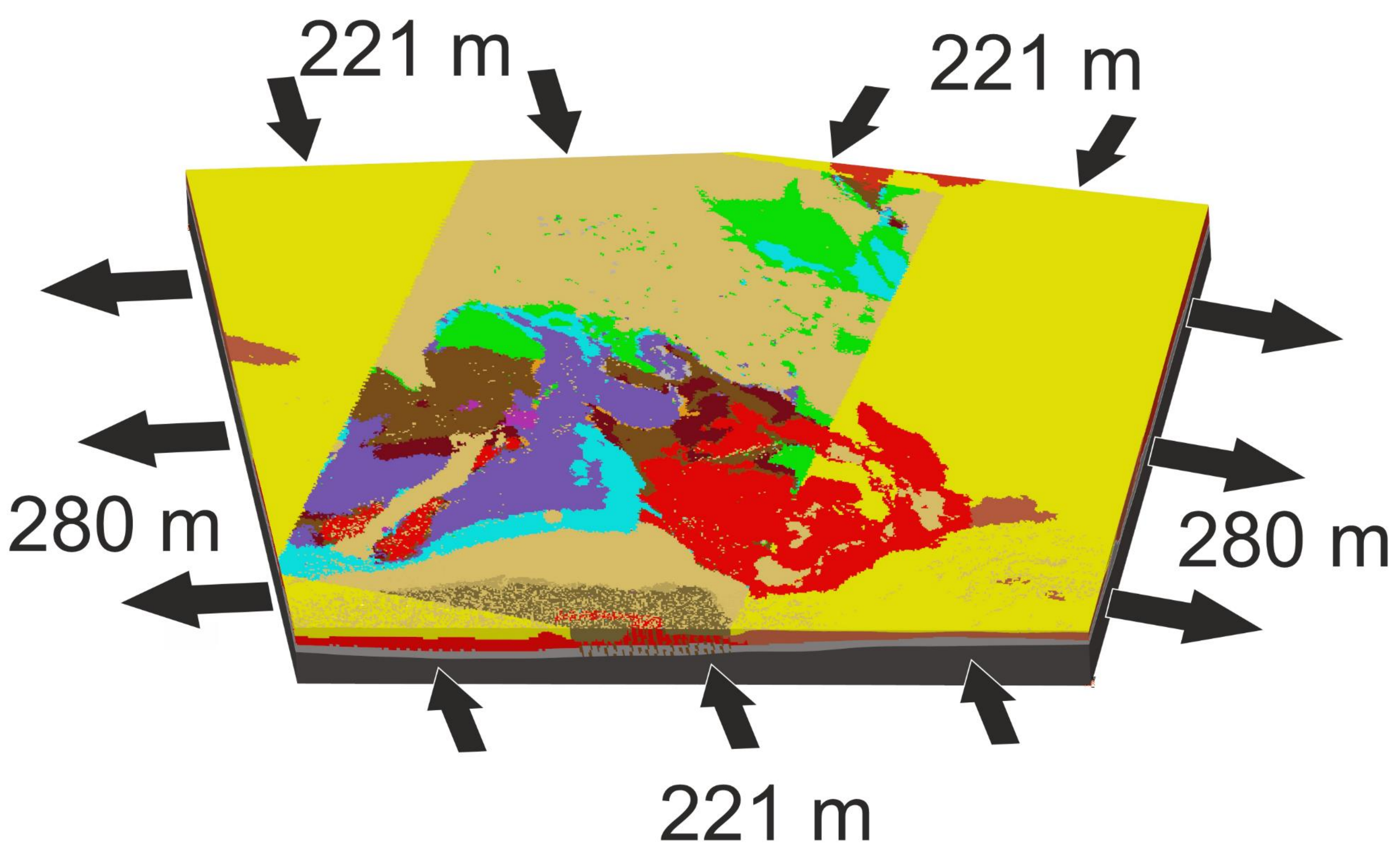


Figure 2: Top view of the geomechanical numerical model of Ahlers et al. 2022. Arrows indicate directions of the displacements applied, numbers the magnitudes of displacements defined for the best-fit.

Results of the geomechanical-numerical model

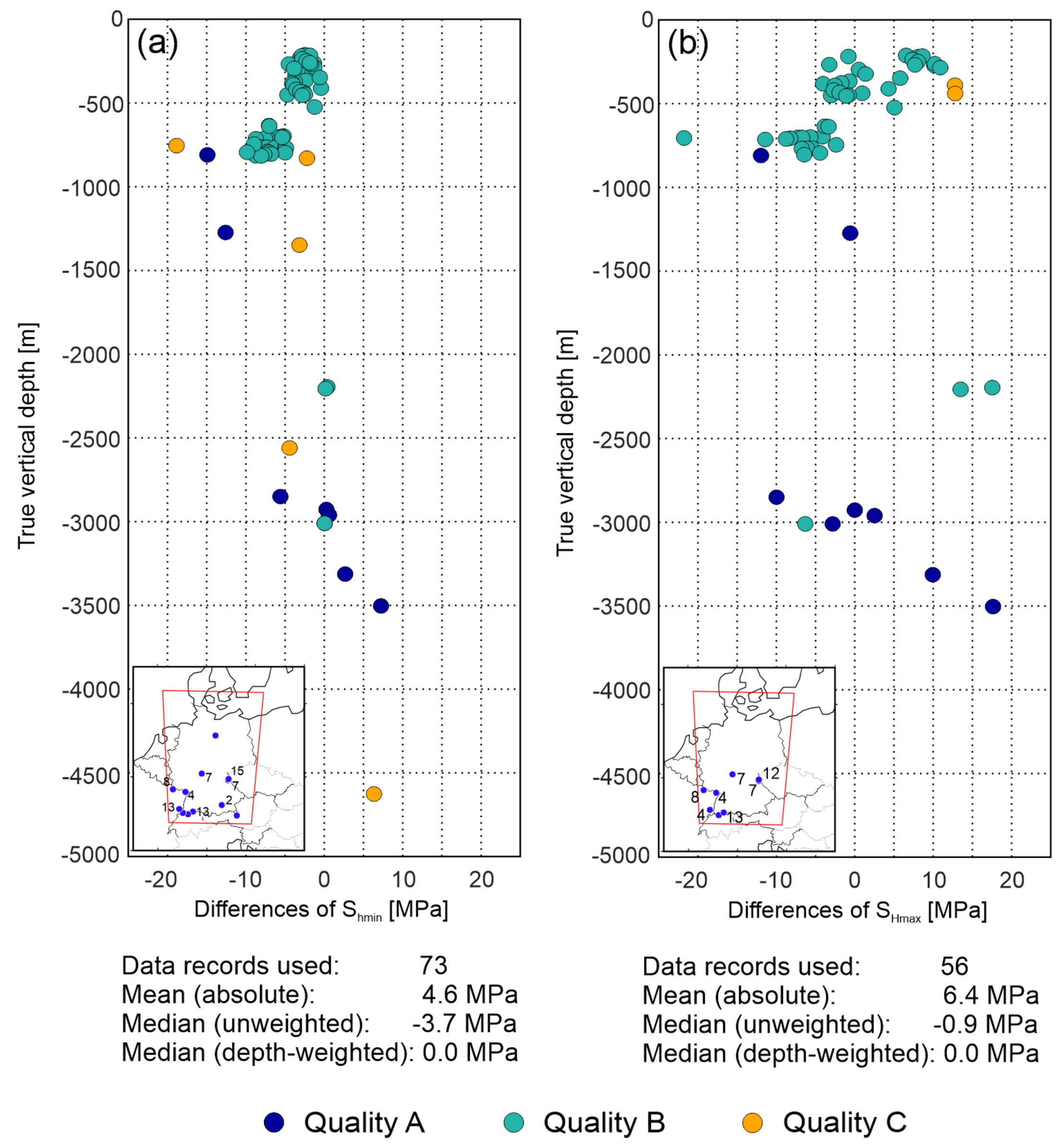


Figure 3: Comparison of model results and calibration data. Differences are calculated as model results minus calibration data. Small maps show the lateral distribution of the data records used. Numbers indicate localities with multiple data. (a) Differences of S_{hmin} magnitudes. (b) Differences of S_{Hmax} magnitudes. (Ahlers et al., 2022)

The model results show an overall good fit with stress magnitude data of S_{hmin} and S_{Hmax} used for the calibration indicated by a mean of the absolute stress differences of 4.6 MPa (S_{hmin}) and 6.4 MPa (S_{Hmax}) as shown in Figure 3. For the calibration process only data records with a quality of A to C and from depths below 200 m (to avoid possible topographical effects) are used. Due to the unequal depth distribution of the calibration data a depth weighted median is choosen as decisive calibration value. The differences are calculated as model results minus calibration data i.e., negative differences indicate too low stresses predicted by the model and vice versa. The results of the S_{hmin} magnitudes (Figure 3a) show a scattering from -20 to 10 MPa with a trend towards too low stresses in the upper 1.5 km. The S_{Hmax} magnitudes (Figure 3b) show a larger scattering of -20 to 20 MPa but no depth dependency.

Figure 4 shows the predicted orientation of S_{Hmax} (red lines) in 5 km depth in comparison to mean S_{Hmax} orientations (black lines) derived from the WSM (Heidbach et al., 2016). The mean WSM data are calculated on a 0.5° x 0.5° grid using the stress2grid script of Ziegler & Heidbach (2019). For each grid point at least ten data records with a quality of A to C within a radius of 200 km are necessary. The comparison shows that the model results lie almost entirely within the standard deviation (grey wedges) of the mean WSM data. However, some regions show clear deviations e.g., clockwise rotations in northwestern Germany or anti-clockwise rotations in central Germany.

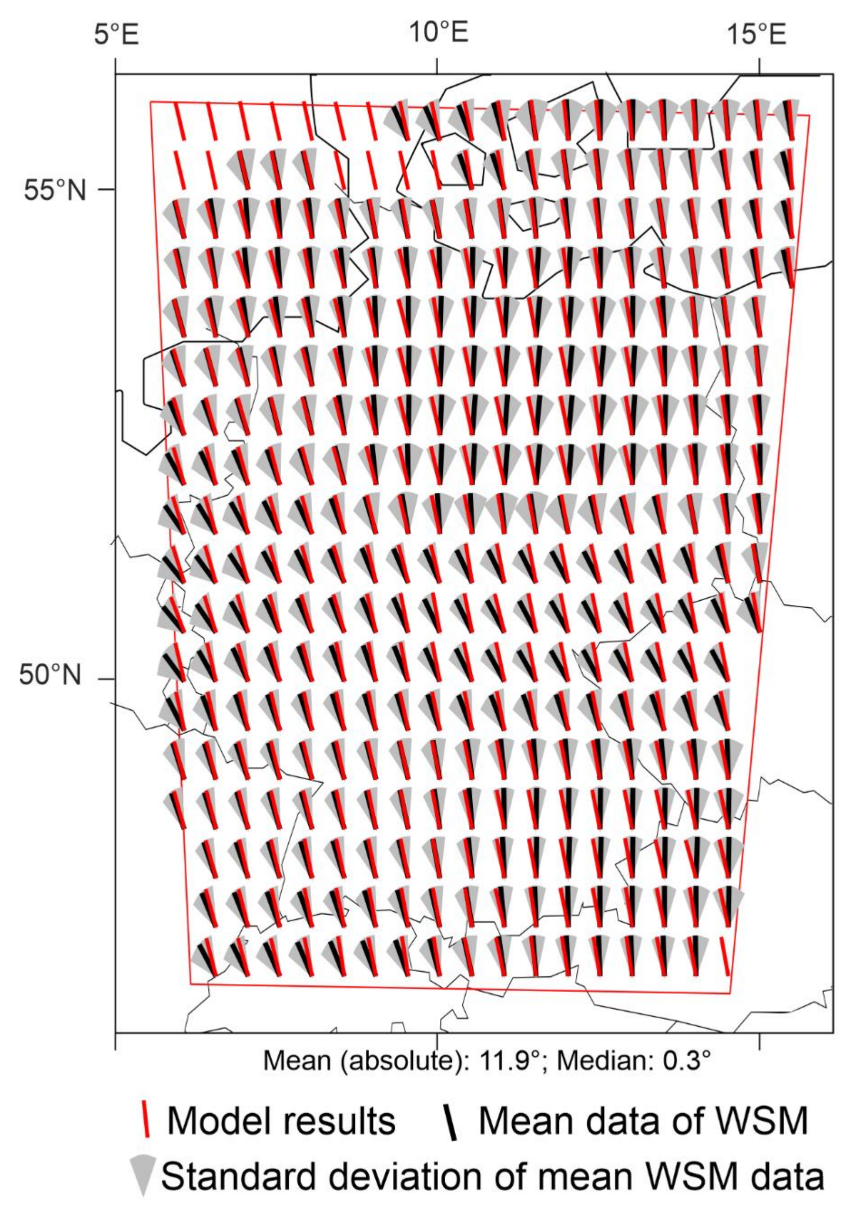


Figure 4: Orientation of S_{Hmax} predicted by the model in 5 km depth (red lines) in comparison to mean data (black lines) derived from the World Stress Map (Heidbach et al., 2016). Grey wedges indicate the standard deviation of the mean WSM data. (Ahlers et al., 2022)

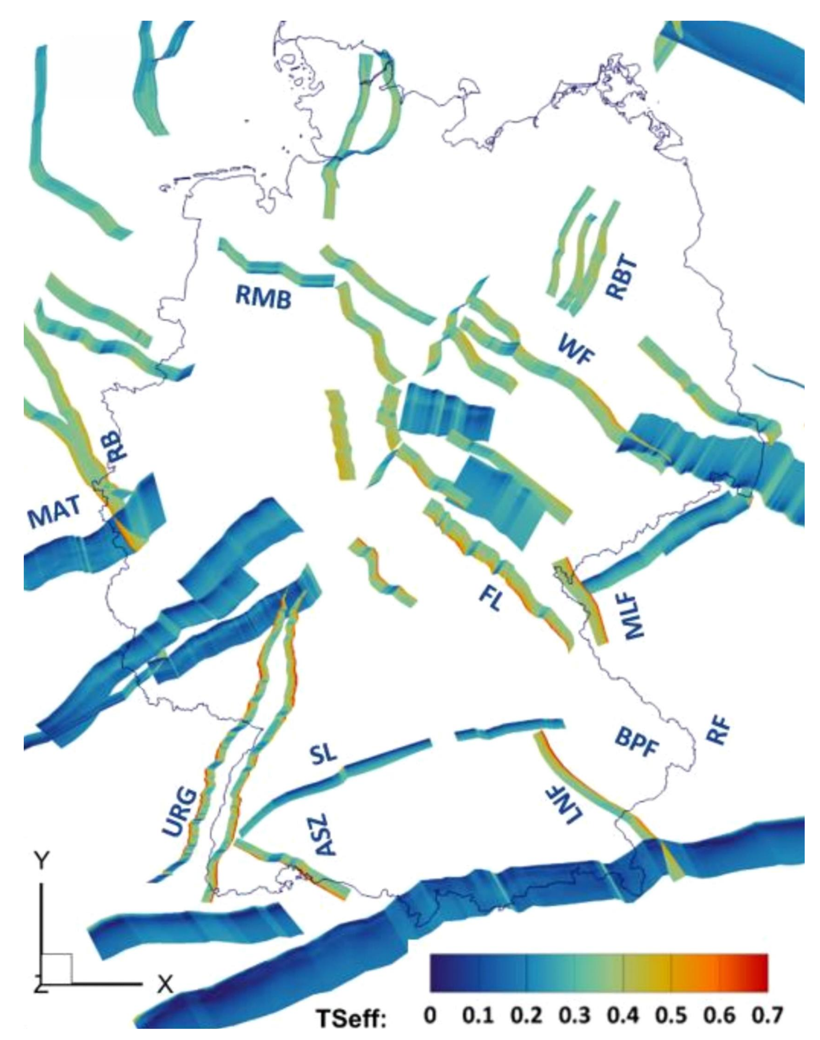


Figure 5: Slip tendency analysis for a semi-realistic fault set of major faults in Germany. A hydrostatic pore pressure is assumed. ASZ: Albstadt Shear Zone (not visible in map view due to the vertical geometry); BPF: Bavarian Pfahl Fault; FL: Franconian Line; LNF: Landshut-Neuoetting Fault; MAT: Midi-Aachen Thrust; MLF: Mariánské Lázne ; URG: Upper Rhine Graben; RB: Roer Basin; RBT: Rheinsberg Through; RF: Rodl fault; RMB: Rheder Moor-Blenhorst Fault; SL: Swabian Lineament; WF: Wittenberg Fault. (Röckel et al., 2022)

Although the geomechanical-numerical model does not contain any faults, the results can be used for the prediction of the slip tendency of faults (Röckel et al., 2022). Figure 5 shows a set of major faults in Germany with calculated slip tendencies. The geometry of the faults is semi-realistic i.e., the dip of the faults depend on their Andersonian fault type (Thrust faulting = 30°, normal faulting = 60 °, strike-slip = 90°). For the calculation effective stresses assuming a hydrostatic pore pressure are used.

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