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Towards structure-based joint geological-geophysical inversion for improved characterization of geothermal reservoirs

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Proper characterization of geologic structures that host geothermal systems is crucial for the efficiency and safety of their energy production. This includes estimating layer boundaries, complex geologic features, and lithology through means of inversion and its regularization. However, existing advanced regularization techniques (e.g., geostatistical regularization, minimum-gradient support, etc.) fail to capture the complexity of 3D geological models including fault networks, fault–surface interactions, unconformities, and dome structures. Förderer et al (2021) propose a solution by means of structure-based inversion, which implements implicit geological modeling and low-dimensional parametrization to produce sharp subsurface interfaces in 2D. This work aims to extend their approach to image realistic and complex geometries in 3D. We continue with the example of electrical resistivity tomography (ERT) and synthetic data; however, this approach is aimed towards independent and joint inversion of geophysical methods that are commonly used in geothermal exploration such as magnetotellurics, gravity, and seismic techniques.

The 3D geological model is created using GemPy, an open-source Python library, which constructs a structural geological model from interface points and orientations using an implicit approach based on co-kriging (de la Varga et al., 2019). Subsequently, the 3D model is discretized, and physical parameters are assigned using minimal pilot points that are then interpolated. We use pyGIMLi (Rücker et al., 2017), another open-source multi-method library for geophysical modelling and inversion, to perform a structure-based inversion, where we include the interface points in the primary model vector of the inversion to update these points iteratively to estimate a geological model in agreement with the geophysical observations.

In this work, special focus is placed on the sensitivity of each model parameter. To maintain low parametrization and account for the increase in computational power, the cumulative sensitivity is calculated and tested under criteria to optimize the model updates. This is relevant for geometries where the interface and pilot points are more influential in one dimension than others. The workflow has also been adapted to include more complex structures that can be defined in 3D, especially those that reflect geothermal systems. This work is part of the Innovative Training Network EASYGO (www.easygo-itn.eu), which aims to improve the efficiency and safety of

geothermal operations but can be readily used in other applications.

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