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Inferring rheology and geometry of subsurface structures by adjoint gradient based inversion of principal stress directions

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Imaging subsurface structures, such as salt domes, magma reservoirs or subducting plates, is a major challenge in geophysics. Seismic imaging methods are, so far, the most precise methods to open a window into the Earth. However, the methods may not deliver the exact depth or size of the imaged feature and may get distorted by phenomena such as seismic anisotropy, fluids or compositional effects.

In geodynamic modelling we solve the Stokes equations to model the high viscous flow behavior of rocks on a large timescale. We take the results of seismic studies as input to the model and then infer or invert for the rheological parameters that satisfy surface observations such as GPS velocities. Obviously, there are many more surface observations, such as gravity gradients, uplift rates or prinicipal stress directions. Here, we extend the inversion framework of the code LaMEM by incorporating stress directions as additional constraints. We use an adjoint-based method to compute derivatives of principal stress directions with respect to material parameters. This enables the usage of two data fields for the inversion - surface velocities and stress directions - as misfit and allows for a more unique determination of material parameters such as powerlaw coefficients or rock densities.

We present numerical results for simplified models of a salt dome with geometrical perturbation and demonstrate that we can infer the existence of such perturbations and its material parameters. We show that this method can be used to further enhance the interpretation of seismic imaging results.