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Joint inversion for thermal and petrophysical properties from wireline and temperature observations

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High resolution temperature logs are extremely useful in geothermal studies but the analysis of their detailed structure requires good control on the thermal properties of the subsurface. This is often achieved by a two step procedure where first thermal conductivity is derived from well logging data and then used to infer the heat flux density of the temperature log. Here, an algorithm is presented that incorporates both steps into a single inversion procedure.

In addition to the petrophysical inverse problem and steady-state heat conduction, transient temperature signals, e.g., originating from past surface temperature change, are included. Computational requirements differ from conventional algorithms for the petrophysical problem because the differential equation for transient heat conduction needs to be solved numerically, resulting in a more complex forward problem.

The inverse problem is solved by a Quasi-Newton iterative scheme, allowing for a Bayesian approach as well as a Tikhonov type regularization. The Jacobian matrix may be calculated either by traditional finite-differences, or by using automatic differentiation. The technique of matrix compression is considered to achieve a most efficient implementation. Matrix compression can drastically improve the computational speed for calculating the Jacobian for certain classes of problems. Those involving transient heat conduction cannot be compressed efficiently whereas purely petrophysical problems have a much higher compression ratio. Results of the algorithm are verified by using well-known programs for paleoclimate and petrophysical inversion.

A borehole in Southern Germany serves as a case study for the algorithm. The algorithm is able to match both wireline and temperature data with good accuracy and in a consistent manner. The ground surface temperature history of the last glacial cannot be reconstructed without ambiguity because the log terminates too shallow for a full reconstruction. An important result is the correlation between the transient temperature perturbation and the shale petrophysical properties which are usually not well-known but may play an important role when transient problems in sedimentary rocks are considered.