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Geothermal Resource Assessment: Combining Uncertainty Evaluation and Geothermal Simulation

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Geothermal resource assessment faces the problem of high degrees of uncertainties for both subsurface geometries and material parameters. We present novel methods for geothermal resource evaluation and their integration into one common framework. This combination enables quantitative assessment of uncertainty and hypothesis testing based on the following four components:

1) Integrated workflow for geological modeling and geothermal simulation;
2) Novel techniques for the spatial analysis of geothermal resource estimations;
3) Spatial map of potential recovery factors;
4) Uncertainty evaluation and hypothesis testing for geological scenarios;

Integrated workflow for geological modeling and geothermal simulation

We have combined multiple steps from the initial construction of the structural geological model, to analysis and visualization of resource estimations into one workflow.

- The structural geological modeling is performed with Geomodeller (Calcagno, 2008), an implicit potential-field approach. This method enables automatic model re-construction for moderate changes in the input data set and is therefore ideal for hypothesis testing and uncertainty simulations.
- The structural geological model is then processed by specialist scripts into a 3-D numerical model for geothermal simulation. We can create input file for TOUGH2 (Pruess, 1991) and SHEMAT (Clauser and Bartels, 2003). Both programs are commonly used for the simulation of geothermal fluid and heat flow fields. SHEMAT simulates fully coupled transport of fluid, heat and reactive transport with a finite difference scheme. TOUGH2 uses a finite volume scheme to solve a variety of transport processes, including multi-phase flow with CO_2 and solute transport.

- Results of the coupled fluid and heat flow simulation with SHEMAT and/ or TOUGH2 are processed with additional own programs for geothermal resource analysis.

Novel techniques for the spatial analysis of geothermal resource estimations

A limitation of standard geothermal resource estimations is the difference in scale for heat in place calculations and estimations of sustainable pumping rates. The total heat in place is evaluated for an entire resource area, based on a volumetric analysis, whereas sustainable pumping rates are examined for a single location, based on assumptions of the subsurface parameters (aquifer thickness, fluid and hydraulic properties) at this point in space.

We have developed techniques to evaluate heat in place and sustainable pumping rates at every location, integrating over properties in a column of limited surface extent everywhere within the resource area. We introduce a heat in place density where the heat for a column of finite volume is evaluated everywhere within the discretized domain.

The next step is the evaluation of sustainable pumping rates, using the estimations of Gringarten (1978) and the extension of Lippmann and Tsang (1980). Performing this analysis on a raster over the whole resource area, we obtain a map of theoretical sustainable pumping rates for a defined well spacing, a maximum pressure drawdown between the wells and a minimum lifetime of the system before thermal breakthrough occurs.

Spatial map of potential recovery factors

From the evaluation of sustainable pumping rates, we can estimate the total amount of produced heat during the lifetime of the project. Combined with the heat in place density, we can derive a potential recovery factor for the geothermal resource as a map view. We consider this value as an important indication for the location of highly promising areas within the resource.

Uncertainty evaluation and hypothesis testing for geological scenarios

In order to evaluate the influence of structural uncertainty on geothermal resource estimation, we combine the previous steps of integrated geological modeling and geothermal simulation, and the spatial mapping of relevant resource properties, with an uncertainty simulation for geological models (Wellmann et al., 2010). Based on quality estimations of the geological input data we create a variety of possible geological input data sets, honoring probability distributions.

Application

We are applying the workflow to a potential geothermal resource area in the North Perth Basin, Western Australia. The Perth Basin is a half-graben structure, filled with thick layers of permeable sediments. Our example model is situated around an interpreted seismic cross section and covers an area of 45 km x 10 km. We have perturbed the geometries around the uncertainties of the seismic interpretations and display here two possible scenarios (Fig. 1).

Looking at the map analyses of heat in place density, sustainable pumping rates and recovery factors we can clearly identify two alternative solutions. The only difference between the two solutions is due to the small perturbations in the geological model.

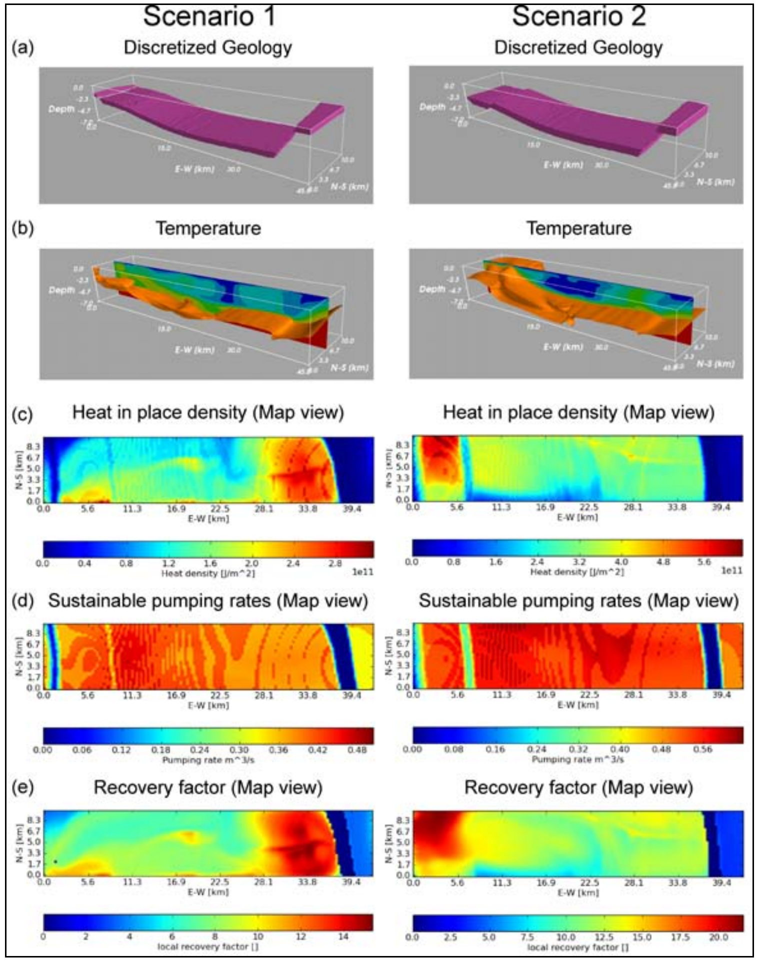

Figure 1: Two possible geological scenarios with a slightly different thickness of the geothermal target unit; (a) Discretization of the target unit; (b) Simulated temperature fields (isosurface of 80°C); (c) Map view of heat in place density: note the two very different possible solutions; (d) Map view of sustainable pumping rates, relatively similar for both scenarios; (e) Estimated recovery factors, strongly reflecting the two possible solutions.

Discussion

The example application illustrates that small uncertainties in the geological structure can have significant impact on geothermal resource estimations. It is therefore important to resolve a priori the possible solution space of geological models before embarking on costly drilling operations. With our workflow, we provide a method to evaluate these uncertainties, thereby reducing the risk for geothermal exploration.

An additional feature of our workflow is that the implementation allows near real-time update of the model inputs and fast prediction of reservoir scenarios. Our goal is to provide a reservoir update during drilling.

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References

Calcagno, Philippe; Chilès, Jean-Paul; Courrioux, Gabriel; Guillen, Antonio. Geological modelling from field data and geological knowledge: Part I. Modelling method coupling 3D potential-field interpolation and geological rules. Recent Advances in Computational Geodynamics: Theory, Numerics and Applications. *Physics of the Earth and Planetary Interiors* **2008**, *171* (1-4) 147–157.

Clauser, Christoph; Bartels, Jörn. *Numerical simulation of reactive flow in hot aquifers: SHEMAT and processing SHEMAT;* Springer: Berlin, **2003**.

Gringarten, Alain C. Reservoir lifetime and heat recovery factor in geothermal aquifers used for urban heating. *Pure and Applied Geophysics* **1978**, *117* (1) 297–308.

Lippmann, M. J.; Tsang, C. F. Ground-Water Use for Cooling: Associated Aquifer Temperature Changes. *Ground Water* **1980**, *18* (5) 452–458.

Pruess, K. *TOUGH2: A general-purpose numerical simulator for multiphase fluid and heat flow*, Technical Report Lawrence Berkeley Lab., CA (United States), **1991**.

Wellmann, J. F.; Horowitz, F. G.; Schill, E.; Regenauer-Lieb, K. Towards incorporating uncertainty of structural data in 3D geological inversion. *Tectonophysics* **2010**, *490* (3-4) 141–151.