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DOI
10.3997/2214-4609.202210828

Publication date
2022

Document Version
Final published version

Published in
83rd EAGE Annual Conference & Exhibition

SKETCH-BASED GEOLOGICAL MODELLING AND FLOW DIAGNOSTICS FOR GEOTHERMAL AND HEAT STORAGE APPLICATIONS

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Summary

Production of subsurface heat from geothermal sources and subsurface storage of heat (and cool) are important for energy transition. Doublets for geothermal and warm- and cold wells for aquifer thermal energy storage (ATES) depend on circulation of fluids and heat. Estimating the potential and feasibility of such systems requires a careful analysis with simulation of fluid flow and heat transport. As building models and running simulations are time-consuming, a prototyping approach is beneficial to quickly assess viability and sensitivity of such systems.

Sketch-based geological modelling combined with flow diagnostics forms the ideal for such a prototyping approach. Geological models can be sketched in 3D in a couple of minutes. Flow diagnostics then provides several key metrics on predicted flow behaviour. The quick turnaround time from sketching to quantitative results is key to understand the impact of heterogeneity on flow and helps to decide which detailed geological models and flow simulations are useful to carry out. This prototyping approach is applied to aquifers in shallow marine deposits, as proxy for thermal breakthrough time in geothermal doublet system and to estimate well spacing between cold and hot wells for ATES.

Sketch-based geological modelling and flow diagnostics for geothermal and heat storage applications

Introduction

Production of subsurface heat from geothermal sources and subsurface storage of heat (and cool) are becoming more important as energy transition progresses. Doublets for geothermal fields (Crooijmans et al., 2016) and warm- and cold wells for aquifer thermal energy storage (ATES; Bloemendal et al. 2015) depend on circulation of fluids and heat. Estimating the potential and feasibility of such systems requires a careful analysis with simulation of fluid flow and heat transport. As building models and running simulations are time-consuming, a prototyping approach is beneficial to quickly assess viability and sensitivity of such systems.

Sketch-based geological modelling combined with flow diagnostics forms the ideal for such a prototyping approach (Jacquemyn et al., 2021). Geological models can be sketched in 3D in a couple of minutes. Flow diagnostics then provides several key metrics to quantitatively assess impact of geology and engineering decision on predicted flow behaviour. The quick turnaround time from sketching to quantitative results is key to understand the impact of heterogeneity on flow and helps to decide which detailed geological models and flow simulations are useful to carry out.

Methods

Rapid Reservoir Modelling (RRM) integrates a sketch-based interface and modelling, with geological operators and a flow diagnostics module (Jacquemyn et al. 2021; Jackson et al. 2015). Sketches are drawn on one or more 2D cross sections are combined into 3D surfaces (Figure 1). Geological operators ensure correct truncations are applied between different these 3D surfaces by the modelling engine. Flow diagnostics then provide a series of metrics to assess how heterogeneity impacts flow (Figure 1)(Zhang et al., 2017; Zhang et al., 2020).

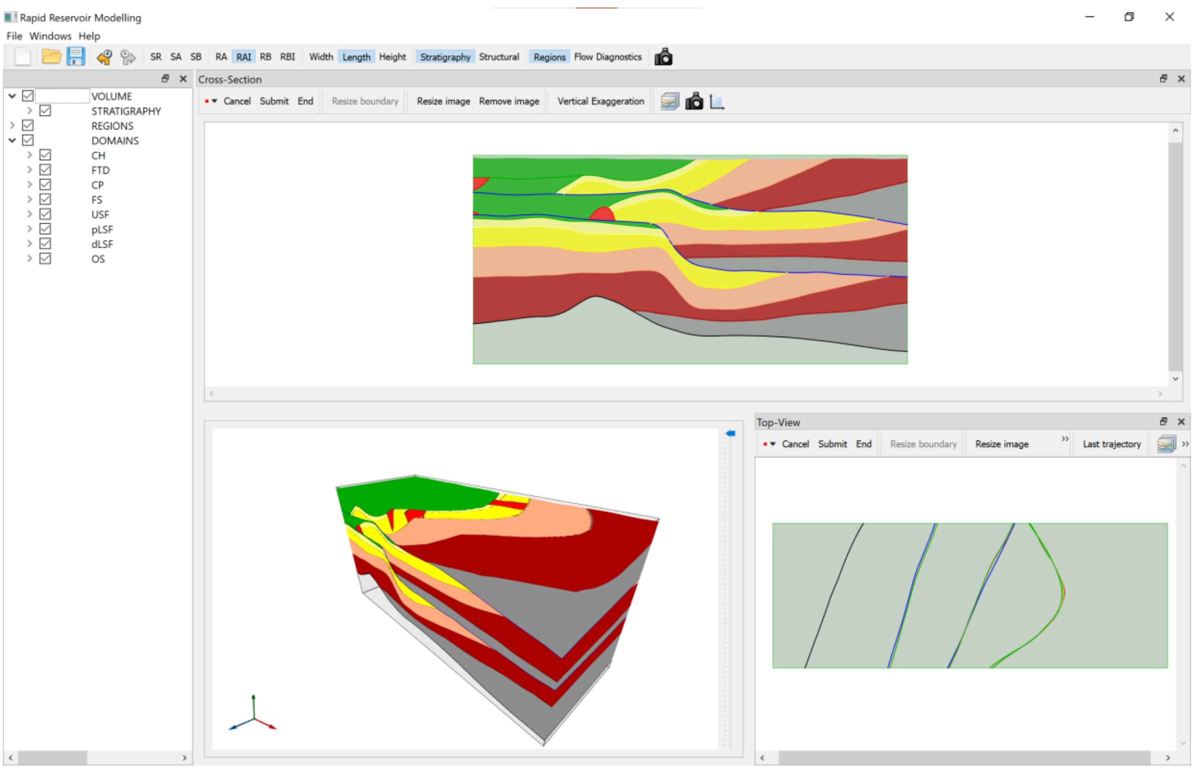

Figure 1 *Screenshot of the sketch-based interface of RRM, showing the cross section sketching canvas (top), map view sketchg canvas (bottom right) and perspective view (bottom left). The sketched model corresponds to model SM5 in case study below.*

Case study

High-permeability aquifers, such as in shallow marine or fluvial sandstones, are key targets for heat production or storage. Connectivity between geothermal well doublets or ATES systems will be impacted by sedimentological heterogeneities. We use the scenarios sketched in Jacquemyn et al. (2021) to show the impact of heterogeneity. Five models are based on different sketched correlations and depositional concepts between 5 boreholes (figure. 2) in shallow marine rocks of the Spring Canyon Mb., Blackhawk Fm. in the Book Cliffs, USA. SM1 represents initial interpretation, SM2 assumes a shorter facies interfingering length, SM3 represents an undulating rather than a straight shoreline, SM4 adopts disconnected flood tidal deltas and SM5 has tidal channels in the upper parasequence.

First a geothermal doublet is considered, with one well completed in the proximal, higher permeability rocks, and the second well completed in more distal, lower permeability, rocks. Flow diagnostics allows to quickly compute the breakthrough time of a tracer released in an injector to reach a producer using Time-of-Flight (ToF; Natvig, 2007, Moyner et al. 2015). This measure can be used as a proxy for e.g. thermal breakthrough time. This is of course a simplification but a valid first order estimate, on which decisions can be made what the most valuable detailed models to build and simulations to run are.

Doublet well spacing is 4 km. Flow rate is set at 800m^3/h, and breakthrough times are calculated from well 1 to well 2 and vice versa. Results are shown in figure 2. For scenarios SM1 to SM4, break well1 to well 2 breakthrough times are approximately 8 years, however in scenario SM5, breakthrough time is 10.49 years. This is probably due to the presence of a tidal channel in the top of the model that distributes the injected water over a larger volume as multiple flow paths exists. For scenario. Breakthrough times from well 2 to well 1 are on average 6 years. Breakthrough time for scenario SM3 is 18.56 years, around 3 times more. This scenario represents a variation in the coastline trajectory, that alters connectivity between different parasequences.

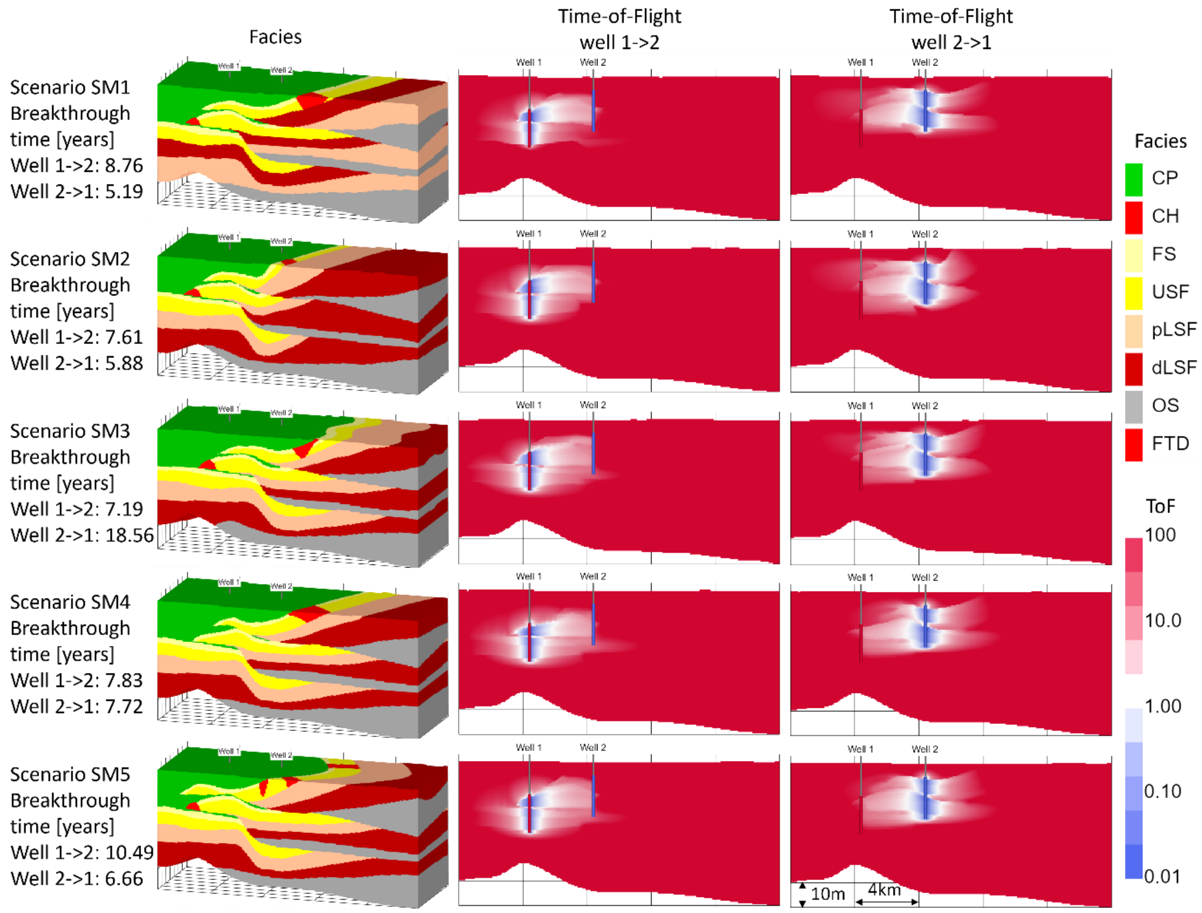

Figure 2 *Flow diagnostics results for a geothermal doublet for all 5 scenarios. Left: perspective view of the 3D models displaying facies; Middle: ToF results from well1 to well2; Right: ToF results from well2 to well1.*

Most scenarios show similar behaviour, and breakthrough times from well 1 to well 2 are generally longer, suggesting a preferred injection from well1 to delay thermal breakthrough. However scenario SM3 deviates from this, and based on this model prototype is worth further investigation, e.g. by detailed modelling and simulation. Breakthrough time in model SM5 is longer than SM1-SM4 and would be a candidate for detailed modelling and simulation too.

Next an ATES system is considered with two wells, one cold and one hot. In the cold season, cool water is injected in the cold well and warm water is produced from the hot well. In the warm season, this is reversed, and cool water is extracted from the cold well, and warm water injected in the hot well. Important for such an ATES system is to prevent interaction between the cold water and hot water plumes. The hydraulic radius of each of the wells can be computed by flow diagnostics, as Time-of-Flight within a 6-month period from both wells. If overlap exists between the computed ToF at 6 months for the cold and hot well, interaction between the cool and warm plume is likely.

Here we show how the interference of cold and hot wells can be avoided in heterogeneous aquifers, corresponding to SM5 in the previous geothermal example. The spacing between both well is gradually increased until the time-of-flight with a threshold of 0.5 years no longer overlaps (Figure 3). Because flow diagnostics calculations happen in seconds, this is a very fast process. This gives a first estimate of well spacing, which forms a good starting point for further analysis.

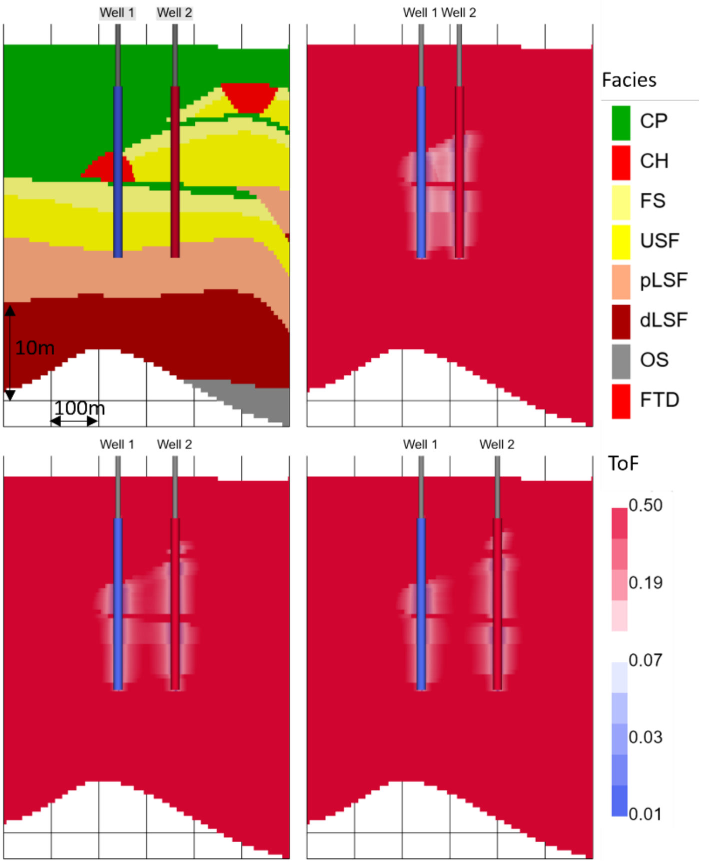

Figure 3 *Flow diagnostics results for increasing distances between cold and hot well pairs in an ATES system in heterogeneous aquifer.*

Conclusions

Sketch-based modelling is a new approach that allows to sketch geological models in 3D. Combined with flow diagnostics module, this allows to quickly sketch models and concepts and acquire quantitative results. Because modelling and flow diagnostics are fast, it is ideal for creating and assessing model prototypes, before detailed and geological models are built, and slow full-physics simulations are set up. In geothermal doublet system, different depositional scenarios are compared to test the impact of heterogeneity on flow and thermal breakthrough. Results indicate a first estimate of breakthrough times and highlights which scenarios should be selected for further analysis. To avoid interference between cold and hot wells in ATES, the spacing between well should be selected carefully. By gradually increasing well spacing the interference between both well could be tested quickly, and a well spacing decided in heterogeneous aquifer.

Acknowledgements

The authors want to thank the members of the Rapid Reservoir Modelling Consortium (Equinor, ExxonMobil Upstream Research Company, Petrobras, Petronas and Shell) for funding this work and granting permission to publish this work. SG acknowledges partial funding for his Chair from Energi Simulation.

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