Using stratigraphic forward modelling to characterise and identify geothermal reservoirs

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The characterisation of geothermal reservoirs is a major issue for the geothermal industry, whether considering Hot Sedimentary Aquifers or Enhanced Geothermal Systems. Assessing the extractable heat from a reservoir requires knowing the extent and the rock properties of that reservoir. At the early stage of exploration, most geothermal companies cannot afford to acquire new data at and therefore rely on previously existing sparse well and seismic data. In those conditions, conventional characterisation techniques cannot be applied and new approaches are required.

In this study, we will explain the principles of stratigraphic forward modelling and how it helps characterise geothermal reservoirs. We will demonstrate the effectiveness of this technique on the Yarragadee Formation in the Perth Basin, and then go through the process of extracting the location and characteristics of potential geothermal reservoirs from the modelling results.

Keywords: geothermal exploration, Sedsim, stratigraphic forward modelling, Perth Basin

Sedsim stratigraphic forward modelling

Stratigraphic forward modelling is a process simulation approach that attempts to replay the way that sediments are deposited. It reproduces numerically the physical processes that eroded, transported, deposited and modified the sediments over varying time periods (Figure 1). Stratigraphic forward modelling has been used in the petroleum industry for more than a decade now (reference needed). It enables a better understanding of depositional mechanisms by testing different geological scenarios or conceptual models. It can predict facies and porosity distributions in areas where well data and seismic surveys are not available.

In this paper, we use the Sedsim three-dimensional stratigraphic forward modelling package that was developed originally at Stanford University by D. Tetzlaff and J. Wendebourg under the supervision of Prof. J. Harbaugh. It has since been modified and extended to the University of Adelaide and CSIRO by C. Dyt (Griffiths and Dyt, 2001). Sedsim enables the

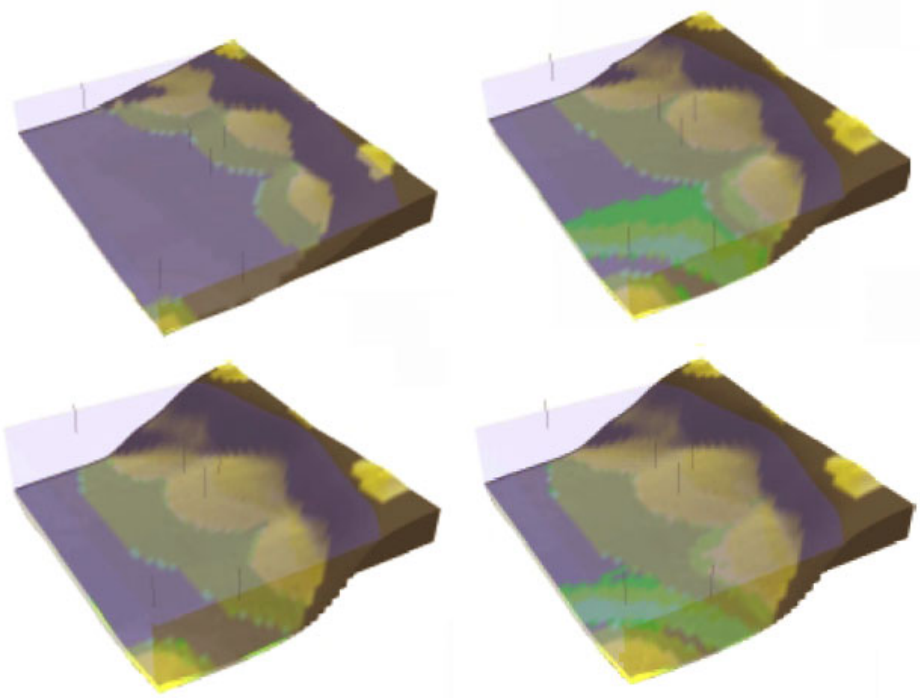

Figure 1: Example of stratigraphic forward modelling results at different time during the deposition (from Young and Griffiths, 2002).

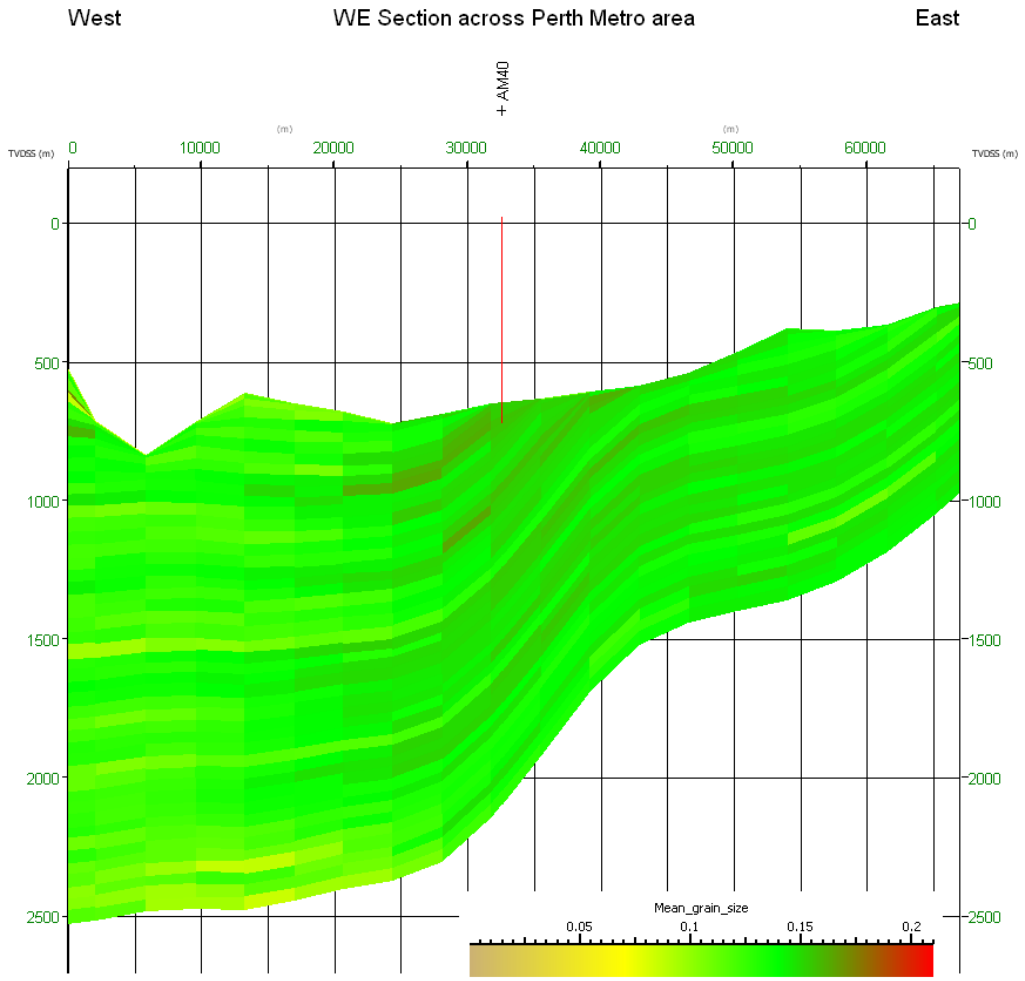

Figure 2: Section across Sedsim model showing mean grain size distribution. The only validation data available in this area was a water bore that only penetrated the first 40 meters of the Yarragadee Formation.

simulation of major depositional processes including marine, aeolian, fluvial, density flow, carbonate, vegetation and others.

Stratigraphic forward modelling of the Yarragadee Formation, Perth Basin

Sedsim stratigraphic forward modelling has been applied to the Perth Basin, in Western Australia, to characterise the Yarragadee Formation. The Yarragadee Formation contains most of the Yarragadee aquifer, which provides a major portion of Perth's drinking water and is currently involved in six direct use geothermal projects (Pujol 2011). Although those projects have demonstrated the geothermal potential of the Yarragadee aquifer, the deeper part of the aquifer is still poorly characterised. We used Sedsim to obtain a better reservoir characterisation without acquiring new data.

The Yarragadee Formation consists largely of sandstones fining up into claystones with coals. The sandstones range from fine to very coarse grains but are mostly medium to coarse with fine grained tops. The Perth Basin during Yarragadee deposition is believed to have been a vegetated floodplain traversed by meandering rivers transporting sediment from south to north, with local inputs of sediment along the sides of the rift forming small alluvial fans and tributary rivers (Tait 2007).

The Sedsim simulation was run over a period of 15.8 Ma, from Middle Jurassic to Late Jurassic. At that time Antarctica, Australia and Greater India still formed one continent. The major sediment source is a fluvial system originating from Antarctica, south of the current Perth Basin. Other minor sediment sources have been simulated originating in the Yilgarn Block, east of the basin and from Greater India, west of the basin. The simulations were run over a regular grid with a horizontal resolution of 3.71 km and a vertical resolution of 250,000 years. The final simulation was validated against well and seismic data where available.

The major outcomes of Sedsim simulations in term of reservoir characterisation are the grain size and porosity distributions. Even for cases where only a limited amount of direct measurements is available, porosity and grain size distributions can be predicted according to the geological history of the basin (see Figure 2).

Identifying geothermal reservoirs from stratigraphic forward modelling

A major question in the assessment of regional geothermal potential is the estimation of the quantity of the accessible resource base that can be extracted, and of the time during which such an extraction can be economically maintained (Gringarten 1978). In this paper, we therefore define a geothermal reservoir based on the amount of heat available in a reservoir and its extractability over a period of time.

To identify geothermal reservoirs, we will compute heat in place and sustainable pumping rates (Wellmann et al., 2011) from the Sedsim forward stratigraphic model results. Heat in place estimates will enable the definition of reservoir bodies. Once the different reservoir bodies are identified, we will compute for each of them sustainable pumping rate for a defined well spacing. We will then combine the sustainable pumping rates of each reservoir with the heat in place estimates to derive a potential recovery factor for the geothermal resource. The recovery factor will then enable the ranking the different reservoirs from an extractability point of view.

Discussion

We successfully applied stratigraphic forward modelling to characterise a poorly quantified sedimentary system in the Perth Basin. Starting from the geological history of the system, stratigraphic modelling simulates the sedimentation through geologic time. It therefore provides a way to estimate the grain size distribution, porosity and permeability based on geological reasoning rather than interpolation between sparse data. The simulated values have been validated against available data from well and seismic surveys. The stratigraphic forward modelling therefore provides insight into, and numerical predictions of, the distribution of sediments and their properties below ground, based on an understanding of the depositional processes involved. These properties can then be analysed to estimate geothermal reservoirs using heat in place and sustainable pumping rates estimates. We anticipate that stratigraphic forward modelling will therefore provide a valuable approach to understanding the subsurface distribution of properties, specifically in areas where data is sparse such as deep aquifers.

To date, stratigraphic forward modelling has already been successfully applied in the petroleum industry. We think that it could also be beneficial for geothermal applications. This will provide a novel way forward for a geologically controlled characterisation of geothermal reservoirs in poorly explored areas.

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