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Integration of Stratigraphic & Rock Physics Models to Generate Synthetic Seismic Data

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SUMMARY

Stratigraphic forward modelling (SFM) is an important subsurface modelling method. A numerical SFM program, such as the Sedsim software used in this study, is able to quantitatively model the sedimentation process with time in order to predict rock properties away from well data.

Although numerical SFM is a powerful technique, it is important to quantify and minimise the uncertainty in the resultant stratigraphic model. This uncertainty can be reduced by producing synthetic seismic traces from the results of the stratigraphic model. This simulated seismic may then be compared to observed seismic over the same area and the parameters of the stratigraphic model modified based on the results of the comparison.

In order to generate synthetic seismic from the results of a stratigraphic model, sediment properties from the stratigraphic model must be converted to acoustic properties. This becomes challenging at inter-well locations, or locations with little or no well control. Fortunately, such conversion can be achieved by the application of a suitable rock physics model even at those challenging locations.

The integration of a Sedsim stratigraphic model and the Velocity-Porosity-Clay (VPC) rock physics model in the Cornea field, Browse Basin, Australia shows the importance of integrating geological and geophysical methods in order to reduce uncertainty when predicting subsurface properties.

Key words: Sedsim, synthetic, rock, physics, integration.

INTRODUCTION

The Cornea Field is an unproduced offshore oil field located within the inner part of the Browse basin. Albian sediments within the Cornea field overlay relatively shallow Proterozoic basement forming a four way dip closure (Figure 1.) (Moby, 2009).

Since the 1997 Cornea-1 discovery well, the Albian sandstones within the Cornea Field and the Browse basin, have become a target for hydrocarbons. Albian sediments in this area range from siltstones to sandstones. The Albian sandstones form isolated sandstone bodies within siltstones and clay-rich sediments. (Figure 2.) In addition, some of these sandstones are non-hydrocarbon bearing. Thus, detecting the Albian sandstones and predicting their hydrocarbon reservoir potential is challenging.

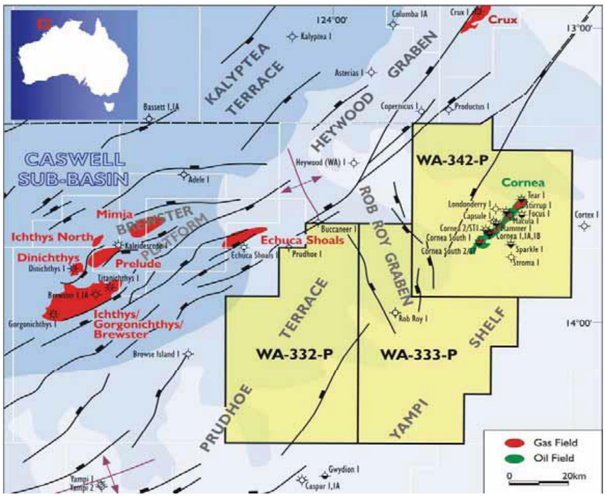

Figure 1. Location of the Cornea field (Moby, 2009).

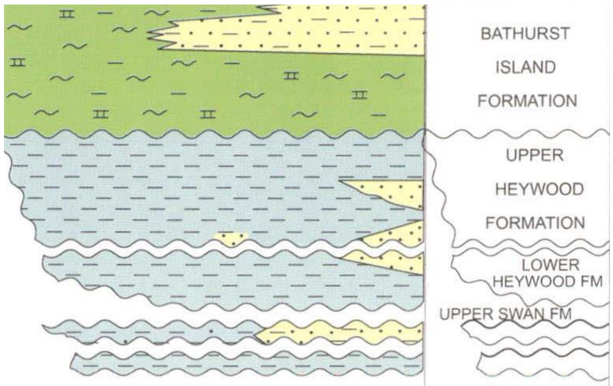

Figure 2. The distribution of the Albian sediments in the stratigraphic column (Geo Australia, 1997).

Since the 1980's oil-field stratigraphic modelling ('static modelling') has primarily used geo-statistical methods. A typical task for a traditional modelling approach is to model variations of sediment properties between two wells by applying geo-statistical methods using data from these wells as input. Unlike a geostatistics-based modelling approach, Sedsim is a numerical hydraulic-process based 3D SFM program. This means that Sedsim quantitatively predicts variations in sediment distribution over geological time as the depositional environment changes. This is achieved deterministically by applying fluid flow equations to a range of geological parameters determined from palaeo-environment and palinspastic reconstruction knowledge over a user-specified geological time interval (Griffiths and Dyt, and Griffiths et. al., 2001).

Several runs are usually required before Sedsim output matches observations to a pre-specified degree at well locations. Before each run, initial input parameters are modified. A process is needed in order to determine whether the output is satisfactory and which parameters to modify. In other words, we need a process by which the uncertainty in the output can be determined. One way of approaching this is by simulating seismic traces from the results of the stratigraphic model. This enables us to compare the results of the stratigraphic model with observed seismic data, which in turn can be used to tune the initial parameters of the stratigraphic model (i.e., closing the loop) and thus reduce the uncertainty of the stratigraphic model.

Seismic forward modelling is a process by which seismic data can be simulated from a stratigraphic model. Traditional seismic forward modelling employs log data from wells to prepare input for the convolutional model at well locations. Geo-statistics is then utilized for inter-well locations. Geo-statistical methods have been accepted as a way to "fill in the gaps" and sometimes give good results. However, they can be associated with large uncertainty, especially in situations where the subsurface geology has significant lateral variation and where there are only a few or no wells. Therefore, a more deterministic approach of preparing the input for the convolutional model is needed.

By applying a suitable rock physics model, the input for the convolutional model can be prepared deterministically independent of well log data availability. Geological information from a stratigraphic model provides input for the rock physics model, which in turn provides elastic parameters for input to the convolutional model. The velocity-porosity-clay (VPC) rock physics model is considered a suitable rock physics model in the case of the Albian sediments of the Cornea Field. The VPC model is a semi-empirical rock physics model designed for sand-shale environments and is an extension of Krief's velocity-porosity model (Goldberg and Gurevich, 1998).

Rock physics can link geological and geophysical parameters. Synthetic seismic data are simulated over the Cornea field by integrating a Sedsim stratigraphic model and the VPC rock physics model. Simulated seismic data are compared to the observed data to modify the initial parameters of the stratigraphic model allowing comparison between the stratigraphic model and the observed seismic and a reduction of uncertainty in the rock properties volume.

Al-Siyabi (2012) attempted to generate synthetic seismic data by integrating the VPC rock physics model and an existing Sedsim-generated stratigraphic model. Al-Siyabi found that the use of a low resolution stratigraphic model and a rock physics model that is unsuitable for the geological properties output by the stratigraphic model can negatively impact the generated synthetic seismic.

METHOD AND RESULTS

The methodology adopted here involved three main stages (Figure 3.):

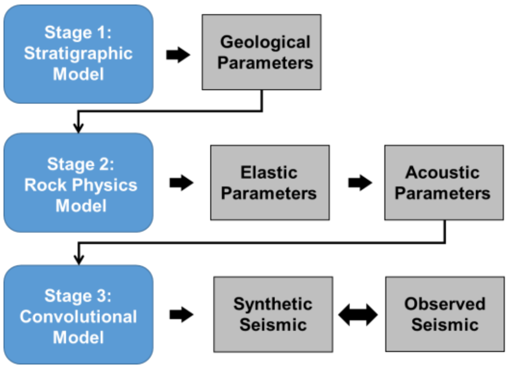

Figure 3. A simple flow chart explaining the methodology. The left-right arrow indicates comparison.

In order to generate a Sedsim stratigraphic model, we needed to prepare the palaeogeographic input required. The input can be divided into two types: geophysical and geological. The geophysical input was minimal. It consisted of a two-way-time seismic horizon of the Proterozoic basement. This horizon was picked from a 3D seismic volume over the Cornea field. Sedsim used the Proterozoic basement as a "base horizon", a horizon used as a starting surface on which stratigraphic layers are deposited (Figure 4.a.).

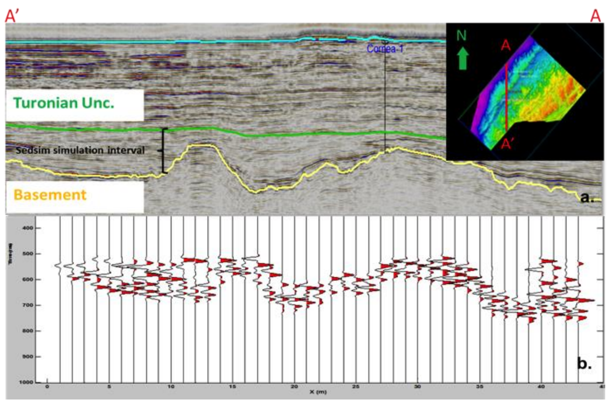

Figure 4. a. Basement 3D time horizon (frame) and line A-A' through the Cornea field 3D seismic data. b. generated synthetic seismic data corresponding to line A-A'. The generated synthetic follows the general trend of the observed seismic.

The geological input includes sediment and river source location, fluid density, fluid velocity, wave direction, and sea level curve. Many of these parameters can be derived from the literature while others involve iterative testing until Sedsim output matches well and seismic stratal geometries to an acceptable degree.

The resultant Sedsim stratigraphic model consists of a grid node volume. Each node contains quantitative information concerning geological parameters such as porosity and grain size (Figure 5. and Figure 6.).

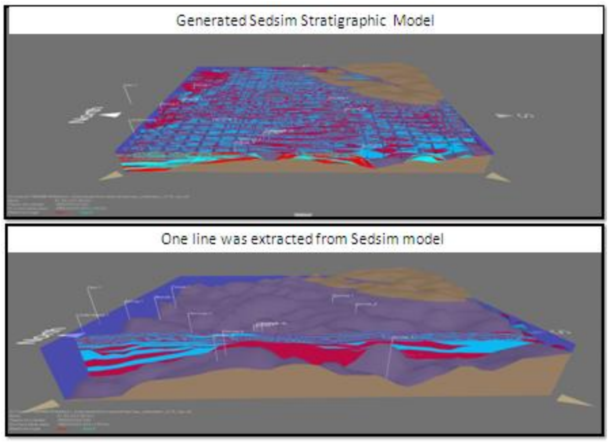

Figure 5. Sedsim stratigraphic model over the Cornea field (top) and a line through it (bottom).

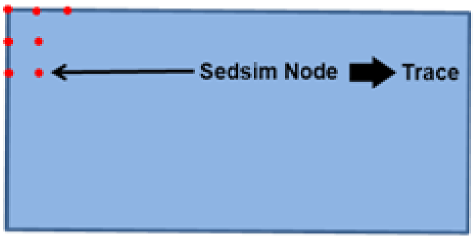

Figure 6. An illustration of a Sedsim node.

For the next step we calculated the bulk modulus K, shear modulus μ and density ρ using the VPC rock physics model. Goldberg and Gurevich (1998) constructed the VPC model to extend Krief's velocity-porosity model from clean sands to clay-rich sands. They achieved this by assuming that the grain material elastic moduli and the dependence of the compliance on porosity are functions of clay content. The VPC model requires as input grain size distribution and total porosity, which we were able to obtain from the Sedsim stratigraphic model.

Once the elastic moduli and density had been calculated, we used them to derive velocities and acoustic impedances at each node. We calculated acoustic impedances as input for the convolutional model and derived reflection coefficients at each node. These were then convolved with a Ricker wavelet to generate a synthetic seismic trace at each Sedsim node where each node corresponds to a seismic trace (Figure 7).

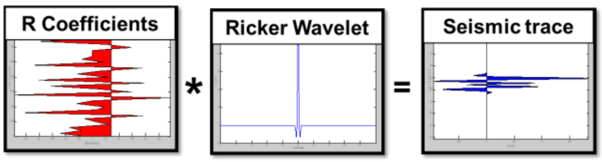

Figure 7. The convolutional model. The star denotes convolution.

After we generated the synthetic seismic data, the next step is to compare it with observed seismic data using lines and traces from both the synthetic and the observed seismic (Figure 4.b. and Figure 8.).

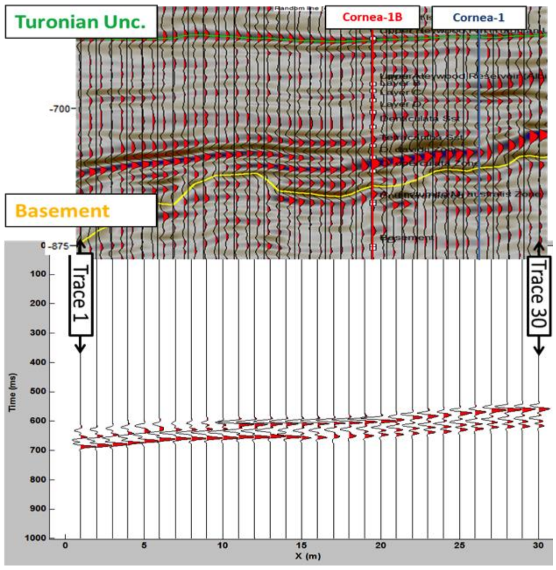

Figure 8. Generated synthetic line (bottom) compared to corresponding observed seismic line (top).

The method successfully produced synthetic seismic data which enabled comparison between the generated synthetic seismic data and observed seismic data. Based on the comparison, we re-ran the Sedsim stratigraphic model after adjusting some parameters such as source density i.e. the result of the comparison helped us reduce uncertainty in the stratigraphic model (Figure 9.).

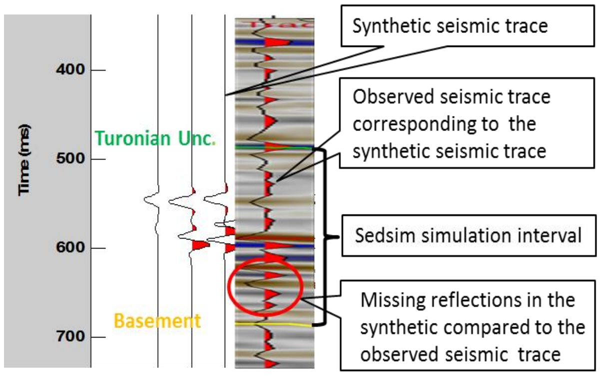

Figure 9. Synthetic vs. observed seismic trace comparison example.

More re-runs will be needed in order to further reduce the uncertainty in the stratigraphic model. In addition, we need to revise the convolutional model to eliminate differences between the synthetic and observed seismic data that may not be linked to the stratigraphic model e.g. seismic time misties. We also need a quantitative seismic comparison method.

CONCLUSIONS

This study shows that the integration of stratigraphic and rock physics models can successfully generate synthetic seismic data comparable to observed seismic data. Numerical deterministic stratigraphic forward modelling is a powerful and quantitative technique for modelling the subsurface but it comes with uncertainty. This uncertainty can indeed be reduced by "closing the loop": modifying the stratigraphic model parameters based on the comparison of observed seismic data and synthetic seismic data generated from the stratigraphic model using a suitable rock physics model. Reducing the uncertainty in the stratigraphic model by the process of "closing the loop" can also be applied to reducing uncertainty in other areas such as stochastic inversion and velocity modelling.

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