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Fining up the seismic stochastically for reservoir characterization, offshore North West Australia

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SUMMARY

The vertical resolution of conventional seismic data limits the illumination and definition of thin sand reservoirs offshore North West Australia. With the availability of more wells within a field it is justified to use a well-centric stochastic seismic inversion approach to characterize the reservoirs. The stochastic AVO seismic inversion yields multiple triplet realizations of acoustic impedance, Poisson's ratio and density at the fine enough vertical sampling for a more relevant reservoir modelling procedure. The paper will discuss the stochastic seismic inversion approach, followed by a structured analysis workflow which condenses the generated multiple realizations to more interpretable data volumes.

Key words: Stochastic seismic simultaneous inversion, realizations, reservoir modelling, volumetrics.

INTRODUCTION

Identifying thin sand bodies for input into a reservoir static model may not always be possible at standard seismic vertical resolutions. By combining the Gaussian simulation methods with seismic AVO inversion algorithms we are able to generate stochastic seismic inversion models that achieve a vertical sampling fine enough to map these sands and ultimately apply to reservoir modelling. Figure 1 Top and Bottom shows the comparison in layer definition between the seismic sample-based acoustic impedance profile with that from the stochastic acoustic impedance.

The large number of stochastic realizations generated from this method of seismic inversion can be daunting, and a method for quantifying the uncertainty inherent in the results is presented.

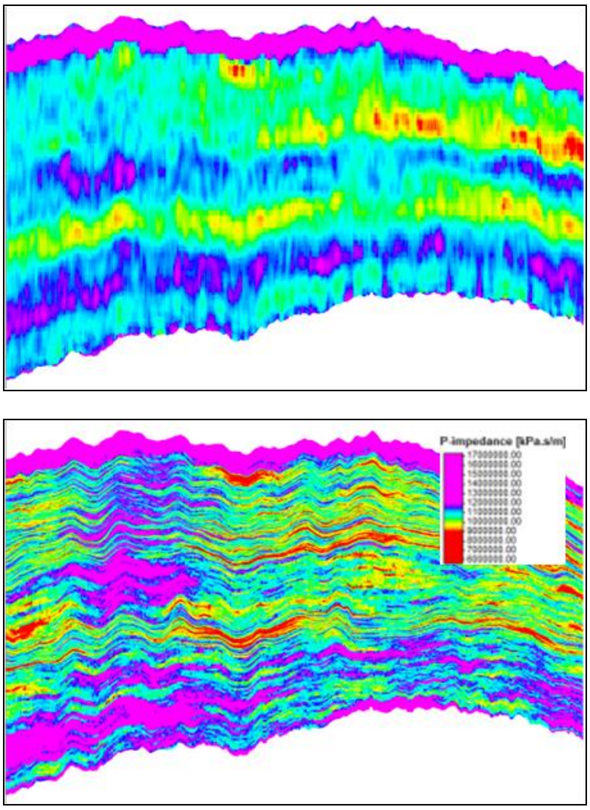

Figure 1 Top: A profile of the deterministic acoustic impedance. Bottom: The same profile from the stochastic acoustic impedance.

METHOD AND RESULTS

The Stochastic Simultaneous Seismic Inversion Approach

The stochastic simultaneous seismic inversion integrates simultaneous seismic inversion with the sequential Gaussian simulation technique. The 3-dimensional semi-variograms for each input property are determined, to adequately describe the spatial variation of the elastic properties away from wells. Figure 2 shows a 12 km range semi-variogram for the lateral continuity of acoustic impedance.

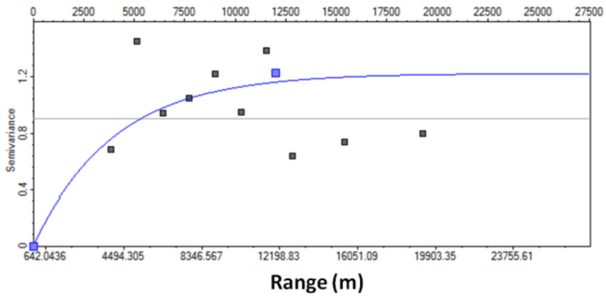

Figure 2: Semi-variogram analysis of Acoustic Impedance data. A 12km exponential semi-variogram is used in this example.

We define a geo-cellular grid in the time domain, using interpreted structural horizons covering the reservoir packages. The areal and vertical dimensions of this geo-cellular grid are set to conform to the static reservoir modelling grid. In this example an areal grid size of 100m x 100m is defined, with vertical cell size of 1ms or 2ms, depending on the reservoir or non-reservoir layers. Figure 3 shows the geo-cellular grid in its skeletal form. The stochastic seismic inversion process populates the realizations directly into this geo-cellular grid framework (Psaila, 2011).

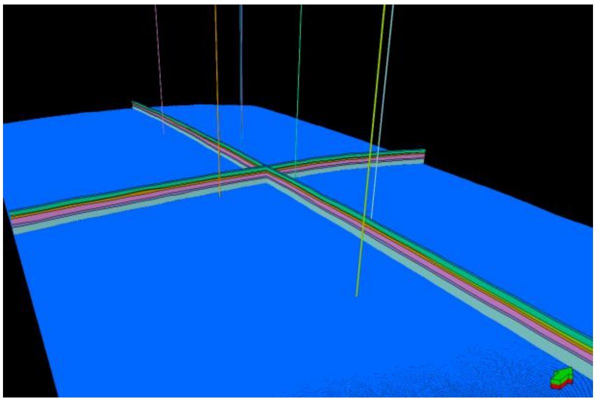

Figure 3: The geo-cellular grid defined with the reservoir layers.

Multiple seismic angle sub-stacks are input to the seismic inversion engine within the sequential Gaussian simulation routine, which yield multiple realizations of triplets of acoustic impedance, Poisson's Ratio and density populated within the geo-cellular grid in a fine enough vertical sampling to be readily integrated into reservoir static modelling without further upscaling required. Typically, around 150 to 300 realizations are generated.

Figure 4 shows the same stratal slice of five different acoustic impedance realizations compared with that from the deterministic seismic inversion, showing the variability of the stochastic process, albeit equi-probable.

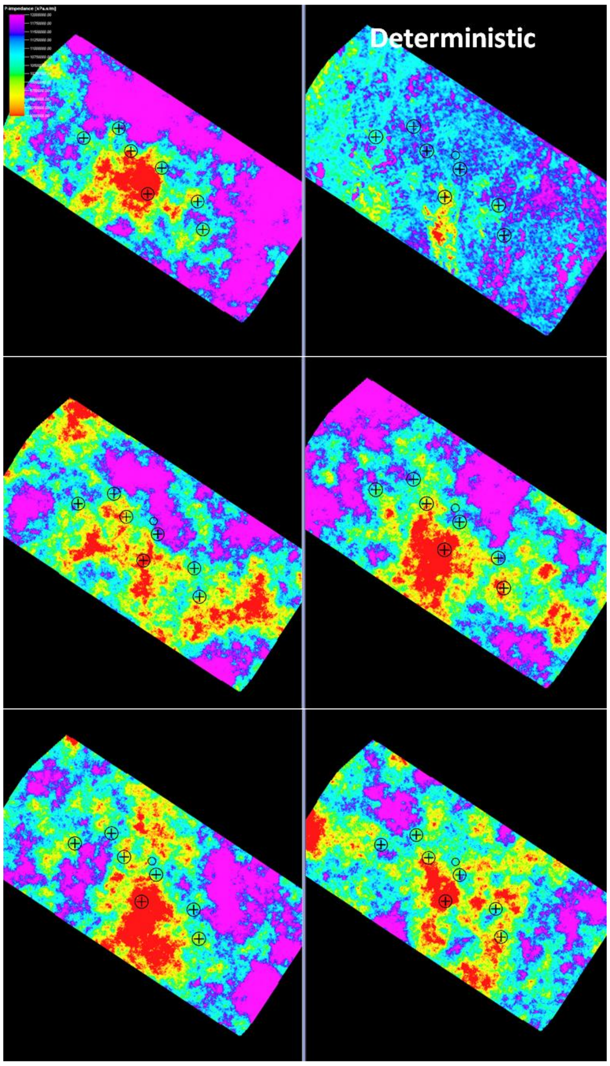

Figure 4: Stratal slice of five stochastic inversion acoustic impedance realizations compared with the same stratal slice of the deterministic inversion acoustic impedance at the top right hand corner.

Data analysis

Whilst deterministic seismic inversion yields one set of answer, the stochastic approach generates a vast number of equi-probable scenarios that are consistent with the input data. The large number of data volume allows us to quantify the uncertainty and spatial variation within the reservoir package.

These realizations can then be sorted according to the desired reservoir model properties such as porosity or pore-volume and ranked as the P10, P50 and P90 cases as input into the reservoir simulator. Criteria to use for sorting and ranking the stochastic simulation results differ with each field, geology and local specifics. Suleiman et al (2012) suggested a methodology whereby the acoustic impedance realizations are transformed to porosity, and then generate indicator data cubes under user specified minimum porosity cut-off conditions. These indicator data cubes are then summed to yield a probability data cube. Subsequently these probability cubes can be applied onto the porosity threshold cubes to isolate the geobodies that fulfil such criteria.

Identifying P10, P50 and P90 Porosity realizations

This work uses the pore-volume ranking approach that has been used in other fields (Ates et al 2005).

The acoustic impedance realizations are transformed into porosity data cubes, then, multiplied with the volume of the cells within the reservoir package to yield realizations in pore-volume units.

Part of the QC steps involved examining the residuals of the porosity transform to ensure that they were normally distributed, and, as such the regression approach is valid.

The porosity realizations are then used to calculate a 'total pore-volume' value for each of the realizations. This consisted of taking the sum of the products of each grid cell volume and its porosity, within the reservoir region and above the water contact, for each of the realizations. The distribution of total reservoir pore volumes could now be analysed. Figure 5 shows the frequency distribution of the pore-volumes. From there it is possible to identify the P10, 50 and 90 cases for input into the reservoir model as shown in Figure 6.

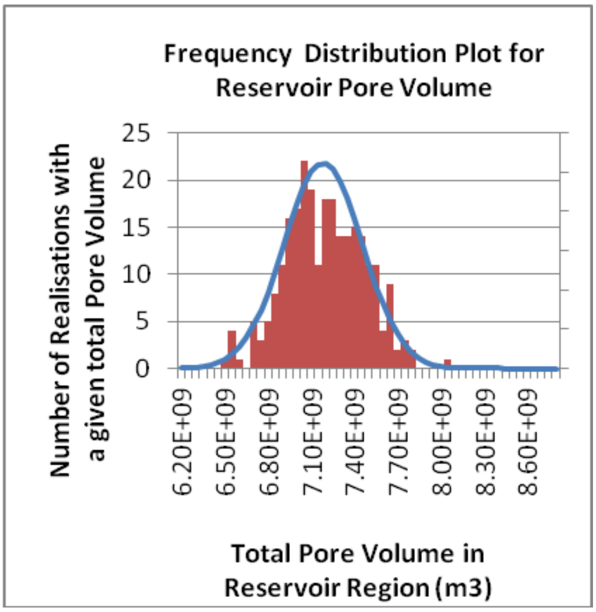

Figure 5: The distribution of realizations of total pore-volume within the reservoir (red histogram). The data appears to be normally distributed (relative to normal distribution in blue curve), consistent with the Gaussian simulation process used to generate the realizations.

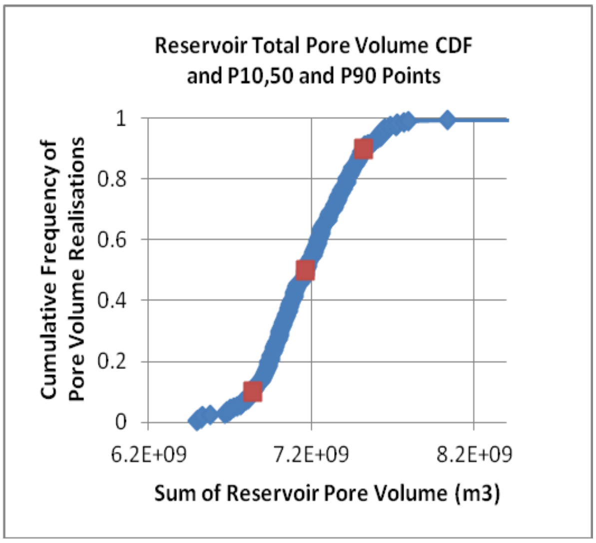

Figure 6: The cumulative distribution function (in blue) showing the P10, P50 and P90 points (in that order from left to right – in red).

The stratal slices from the data cubes that is associated with the P10, the P50 and the P90 entries are shown in Figure 7.

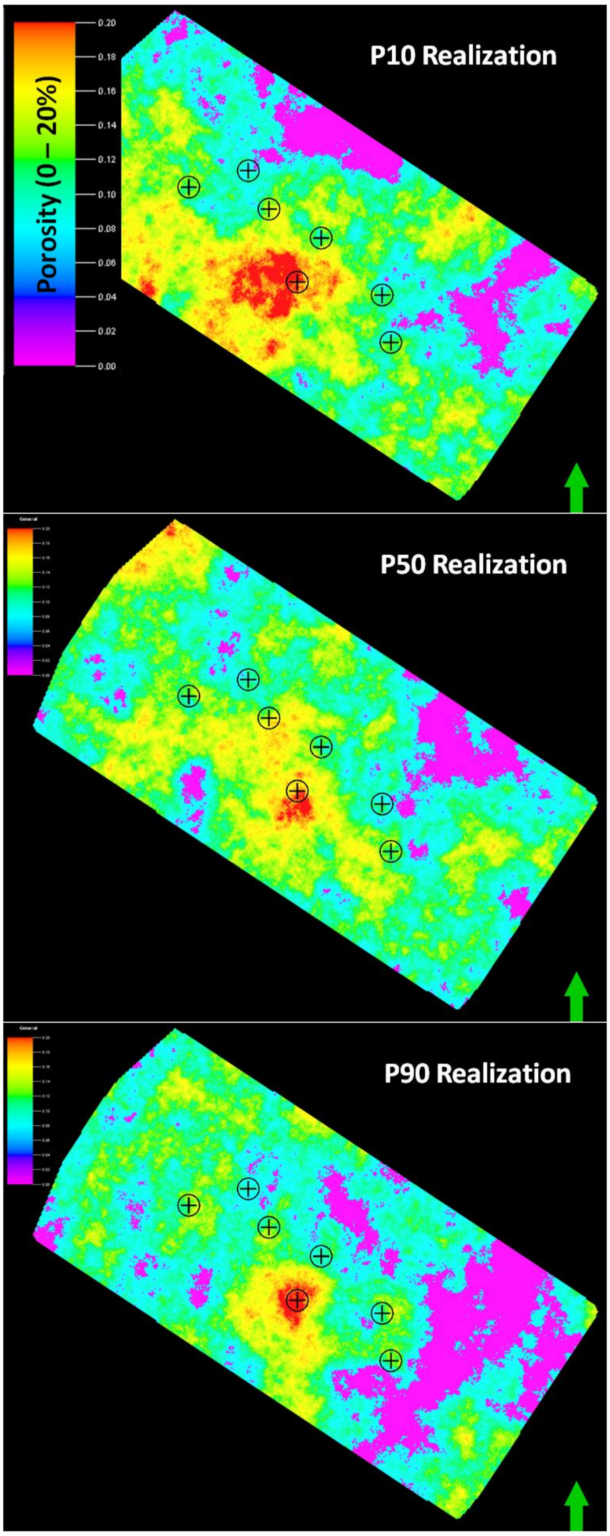

Figure 7: The P10, P50 and P90 cases for the pore-volumes across the same stratal slice.

CONCLUSION

Stochastic seismic inversion provides a method to generate finer vertical sample results that may be used to understand thin sub-seismic resolution sand body distributions. In cases where modelling the continuity of fine sand bodies below the resolution of deterministic seismic inversion is required, stochastic seismic inversion methods provide that link between the fine vertical sampling of the geological model and the good areal resolution of the seismic inversion coverage.

Having generated a vast number of finer resolution seismic elastic property cubes we have shown a way to analyse and rank the data, to identify the P10, the P50 and the P90 realisation as possible inputs to reservoir simulations.

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