High-Resolution Impedance Data for Reservoir Modeling

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ABSTRACT

Property models of absolute acoustic impedance values were built integrating, well, seismic, and geologic data utilizing deterministic and stochastic inversion techniques to aid the development and reevaluation of the Rotliegend Gas Field, northwestern Germany. The acoustic impedance models helped in accurately defining and characterizing the Wustrow and Ebsorf reservoirs in the Rotliegend Gas Field. The 3-D stochastic inversion model contained adequate vertical and lateral resolution and hence was utilized as the soft data to build impedance-dependent facies model and subsequently facies-dependent porosity and permeability models of the Wustrow, Ebstorf and Dethlingen reservoirs. Data from 26 wells in the study area were used in seismic-well tie, wavelet extraction, reflectivity balancing and low-impedance model generation. The deterministic inversion produced pseudo-log of absolute acoustic impedance values at each seismic trace location by spectrally combining the inverted balanced reflectivity trace and the low frequency background model about the transition frequency. The stochastic inversion built upon the work performed during deterministic inversion to create high-resolution acoustic impedance models. The stochastic inversion process generated multiple realizations of the acoustic impedance pseudo-logs at each seismic trace location utilizing sequential simulation algorithms and retained the realization whose seismic response best correlated with the actual seismic trace at that location.

KEY WORDS: seismic inversion, stochastic modeling.

INTRODUCTION

3-D reservoir property models were built with the purpose of re-evaluation and development of the Upper Permian Rotliegend Gas Field in two phases. High-resolution acoustic impedance models were generated using both deterministic and stochastic inversion techniques in the first phase of the study. The impedance-constrained facies models and the facies-dependent porosity and permeability models were subsequently generated using geostatistical algorithms, in the second phase.

The Wustrow and Ebstorf members of the North Hannover Formation, consisting of inter-bedded sand-shale sequence and situated at a depth range of 4500-5000 m, are the two main reservoirs of the Rotliegend Gas Field. The Wustrow member, composed of a thick shoreline sandstone unit, is the primary gas reservoir in this field. Deep-seated Carboniferous coal formations source the Rotliegend reservoirs that are immediately overlain by the Zechstein salt providing the top seal. The reservoir quality in the Rotliegend Gas Field is primarily governed by the diagenetic alteration of the sandstones including cementation of the primary pore spaces by illite, kaolinite, quartz and calcite.

Data Preparation

A migrated 3-D seismic volume, covering approximately 510 km² and containing about 1300 in-lines and 900 cross lines, both spaced 25 m, was available for seismic inversion. Seismic interpretation provided six time markers: Top_A2, Base_Zechstein, Top_Wustrow, Top_Ebstorf, Top_Dethlingen and Base Dethlingen, from top to bottom. Two pseudo markers, one 100 ms above the Top_A2, and the other, 100 ms below the Base_Dethlingen horizon were used as the upper and lower limits of seismic inversion. The deterministic and stochastic inversion utilized data from 26 well in the AOI (Figure 1).
Wavelet Estimation

The well-seismic tie and wavelet extraction process produced the synthetic seismograms, time-depth relation, well logs and markers in time domain and estimated wavelet at each well. The well-seismic tie and estimated wavelet at Well A are displayed in Figure 2.

Deterministic Inversion

The seismic data contained a frequency bandwidth of 8 to 67 Hz. The seismic spectral analysis was followed by application of zero phase deconvolution to the entire seismic volume for spectral whitening to balance the frequency content.

The next step was to perform spectral extrapolation using the sparse-spike deconvolution algorithm that uses a prediction error filter scheme to predict the high-frequency amplitudes based upon the pass-band frequency amplitudes of seismic data (Oldenburg et al., 1983). There exists a reflectivity series with the fewest number of reflection coefficients, i.e., sparse-spicies, that when band-limited to the seismic data pass-band, will approximate the seismic data, according to the spectral extrapolation assumption.

Next, a 3-D amplitude balance model over the seismic volume was created through inverse distance interpolation of the envelopes of the synthetic seismograms at well locations. It is assumed that the well information is a better predictor of amplitude trends than the seismic data. The application of the balance model to the seismic data produced balanced traces scaled to the modeled reflectivity envelopes.

A background model was created in a similar manner utilizing the low-pass filtered impedance logs in time domain saved during wavelet extraction at 26 well locations.

The deterministic inversion was then performed by spectrally combining the inverted balanced reflectivity trace and the low-frequency background model about the transition frequency of 8 Hz to create pseudo-log of absolute acoustic impedance values at each seismic trace location.

Stochastic Inversion

The stochastic seismic inversion technique integrates the fine vertical sampling of the log data with the dense areal sampling of the seismic data to create detailed, high-resolution property (acoustic impedance, density or velocity) models utilizing geostatistical algorithms (Haas and Dubrule, 1994). The purpose of stochastic seismic inversion,
therefore, is to produce the property models at about the same vertical scale of resolution as the well control, but use the seismic information between wells.

Multiple realizations of impedance data are simulated at a seismic trace location within the 3-D framework. Synthetic seismograms for all impedance traces are generated after converting to reflectivity traces and convolving them with an assigned wavelet. The synthetic seismogram with the highest correlation with the actual seismic data is retained as the solution at that particular trace location. A random walk through the 3-D framework selects the next location and repeats the same procedure to produce the inversion solution at that location. This procedure continues until the entire 3-D framework is filled with pseudo logs of acoustic impedance at all seismic trace locations. The geostatistical process described here is called Sequential Gaussian Simulation. This algorithm also permits use of the deterministic inversion impedance volume as the soft data constraint.

The phase-corrected seismic data were scaled using the previously generated amplitude balance model. Subsequently, both the balanced seismic and deterministic data were resampled at 0.5 ms to match the impedance logs generated at 26 well locations during wavelet estimation.

Both azimuth-dependent areal (X-Y) and vertical (Z) impedance variograms were modeled for the seven zones individually.

Stochastic seismic inversion was performed over seven zones bounded by the Top_A2_minus_100ms and Base_Dethlingen_plus_100ms markers using the well impedance as the hard data and the deterministic inversion impedance as the soft data. One hundred equiprobable impedance traces were simulated at each seismic trace location.

The stochastic inversion program is capable of handling poor quality seismic data in selected areas, for example, a salt body or a gas chimney, by using only well data in those areas during inversion. Due to poor seismic data quality within the area influenced by the salt body (Figure 1), the Sequential Gaussian Simulation was permitted to produce only one impedance log at each seismic trace location within this area.

The correlation coefficient map (Figure 3), showing the match between the model (synthetic) trace and the actual seismic data as high as 95 percent, validates the results of stochastic inversion.

The deterministic and stochastic inversion results in one of the seismic lines are displayed in Figure 4 and Figure 5, respectively. Detailed examination of these two products reveal that the stochastic inversion technique provide a better control of the reservoir heterogeneity between wells compared to the deterministic inversion, by virtue of the enhanced vertical resolution. Figure 6 exhibits a close up view of the stochastic (top) and deterministic (bottom) inversion around Well A. The Wustrow reservoir interval, characterized by low impedances could be much better delineated in the stochastic inversion model (Figure 6). In addition, changes in acoustic impedance values indicate variation in porosity and/or fluid type within the reservoir interval. Figure 7 exhibits a map representing the vertical average of impedance values over the Wustrow interval.

Conclusions

Property models of absolute acoustic impedance values were built by integrating well and seismic data performing deterministic and stochastic inversions.

The Wustrow, Ebstorf and Dethlingen reservoirs were accurately defined and characterized in both the deterministic and stochastic inversion impedance models. The stochastic inversion was designed specifically to handle the poor seismic data within the salt influence area, where only one simulation was conducted at each seismic trace location.

The stochastic inversion impedance model provided higher vertical resolution compared to the deterministic inversion model, and hence, was utilized as the soft data constraint in constructing models of facies (lithotypes). The 3-D porosity and permeability models were subsequently created based on the facies and impedance models. Since the well control in the study area is sparse, utilization of the impedance model was of critical importance in modeling the reservoir heterogeneity between wells.
and thereby differentiating the pay - non-pay zones to facilitate the development of the Rotliegend Gas Field.

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References

Gast, R.E., 1988, Rifting im Rotliegenden Niedersachsens, Die Geowissenschaften, v. 6, no. 4, pp. 115-122.

Figure 3. Stochastic Inversion Correlation Coefficient Map.

Figure 4. Deterministic Inversion with the Well A Impedance log overlay.
Figure 5. Stochastic Inversion with the Well A Impedance log overlay.

Figure 6. Stochastic (top) and deterministic (bottom) inversion results around Well A (see Figures 4 and 5).

Figure 7. Map showing vertically averaged impedance values over the Wustrow reservoir interval.

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REFERENCES

