CONDITIONING A FLUVIAL RESERVOIR ON STACKED SEISMIC AMPLITUDES

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SUMMARY.This paper describes a model for conditioning a fluvial reservoir on stacked seismic amplitudes. Synthetic seismic amplitudes are generated from the reservoir model by convolving reflections, and the likelihood for the reservoir with respect to the seismic is computed from the difference between real and synthetic traces. Promising results are achieved in synthetic cases. The improvement was smaller when conditioning to a real data set with smaller amplitude contrasts.

1. INTRODUCTION

Seismic data are becoming increasingly important in conditioning of petroleum reservoirs. An object-based model for simulating fluvial reservoirs conditioned on inverted seismic data, such as impedances, is described in [4] and [3]. The model described here is different in the seismic conditioning since it uses stacked seismic amplitudes which are pre-inversion data. Conditioning on seismic amplitudes makes it easier to get the correct interaction between objects in the seismic pattern. This is due to a larger support volume, as entire seismic traces are considered. In addition, this model can be seen as a kind of seismic inversion conditioned to facies geometries, where the stochastic aspect preserves the non-uniqueness of inversion.

The basic idea is to compare the seismic amplitudes with synthetic amplitudes generated from the simulated reservoir. A good match here will indicate good correspondence between the true and the simulated reservoir. The idea is described in both [1] and [2].

The geometry of the problem may reduce the effect of the assumptions made to generate the synthetic seismic. Since channels are large objects which intersects many traces, small effects add up over large volumes to influence the location of channels.

2. MODEL AND ALGORITHM

The model used here is an object based model for simulating facies in fluvial reservoirs, where the objects are channel sands, placed on a background of shale. The model for a reservoir r given the seismic s, well contacts w and volume constraints γ, is given as

$$\pi(r|s, w, \gamma) = c f_M(r) f_S(s|r) f_I(r) f_W(r) I(r|w, \gamma),$$

where c is an unknown normalising constant. The channel geometry is described by $f_M(r)$, the seismic conditioning by $f_S(s|r)$, the interaction between different channels by $f_I(r)$, the well contacts by $f_W(r)$, and the well and volume constraints by $I(r|w, \gamma)$. The constraint function $I(r|w, \gamma)$ is zero or one, f_M, f_S, f_I and f_W are probability densities.

Stacked seismic amplitudes are used as input data for the seismic conditioning. These are pre-inversion data, representing an approximation of a vertical seismic shot.

Three assumptions are fundamental for the seismic conditioning in this model:

1. The seismic amplitudes can be represented as a convolution of reflections from a vertical trace.
2. The velocity along a trace is constant within the modelled reservoir zone, but may vary between traces. This velocity is only used for time/depth conversion, and is uncorrelated with the impedances.
3. The transition between different facies objects has constant reflection.

These assumptions are used to create synthetic seismic amplitudes. A reflection occurs at locations where the impedance changes, and is given as

$$R_k = \frac{Z_{k+1} - Z_k}{Z_{k+1} + Z_k}$$

where R_k is the reflection at time step k, and Z_k is the impedance. The synthetic seismic amplitude s^{syn} is then generated as the convolution of R with a wavelet w,

$$s_k^{syn} = \sum_{i=0}^{l} w_i R_{k-i+l/2}$$

where l is the length (in time steps). The generation of synthetic seismic is shown in Figure 1.

It is a common assumption in most inversion methods that the seismic signal can be represented as convoluted reflections, so this is similar to existing approaches. Furthermore, no serious errors are introduced by the second assumption. Shale has usually higher velocities than sand, so the thickness distribution for channels is slightly disturbed, but the effect is small. This effect is hard to overcome, as a facies-dependent velocity would change the time-depth relationship every time an object was added or removed. General trends in the time-depth relationship could be included; the essential model assumption here is that the time-depth conversion is independent of the realization.
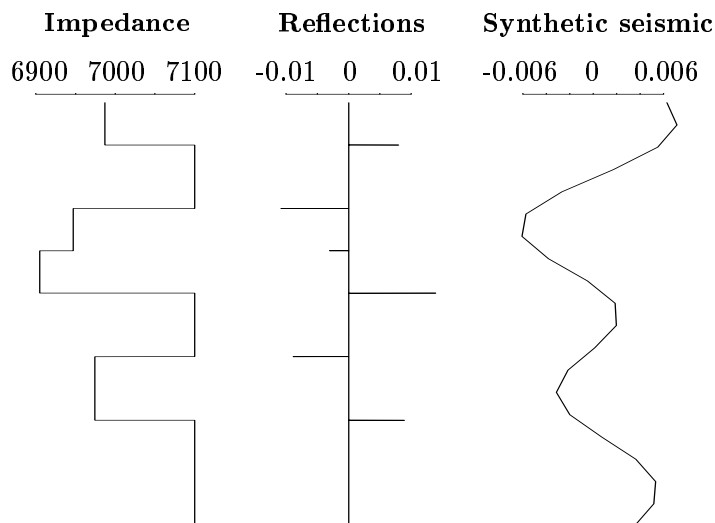

FIGURE 1. The plot shows the impedance along a trace (left), the corresponding reflections (middle), and the synthetic seismic (right).

The third assumption is more critical. Reflections are generated by differences in impedance. Impedance variations inside objects account for much of what is seen in the seismic amplitudes. However, the largest impedance changes corresponds to facies changes, so although some information is lost, the most important information in the seismic data is still utilized. Note that constant reflections can be obtained when there are corresponding spatial trends in the facies objects.

The relationship between real and synthetic seismic amplitudes is given as

$$s = s^{syn} + \epsilon$$

where s are the observed amplitudes, and ϵ is a noise term. The last term includes all kinds of noise, from noise in the signal and interpretation, to parts of the signal which contain information that is not utilized in this model.

In order to get a valid model here, a distribution is needed for ϵ. A common assumption in inversion is that this term is Gaussian. This gives

$$f_{(s|r)} = \exp \left\{ -\frac{1}{2}(s - s^{syn})'\Sigma^{-1}(s - s^{syn}) \right\}$$

where Σ is the covariance matrix for the noise term. However, this matrix is very hard to estimate, so the actual term used in the model is

$$f_S(s|r) = \exp \left\{ -\frac{a}{2\sigma^2} \sum_i (s_i - s_i^{syn})^2 \right\}$$

where σ^2 is the variance of ϵ and a is a scaling factor between 0 and 1.

If the scaling factor was not included, this would be equivalent to assuming uncorrelated noise, which is a very poor assumption here. The scaling factor can be set to give noise with the correct range the correct likelihood. Residuals with shorter range would get too high likelihood, whereas long range residuals would get too low. The first is not a serious problem; as the channels are long-range, going through the entire reservoir, the shortest possible range for the residuals is the range of the noise.

A Metropolis-Hastings algorithm is used to simulate from the model. The initial state is an empty reservoir, and each iteration either adds, changes or removes one channel belt.

In order to quicken convergence in the seismic term, it is used actively in the channel generating algorithm. As the seismic pattern is given by interference between amplitudes from different objects, it is hard to locate channel directly from this. However, areas with large residuals may indicate a lack of channels there. Therefore, such areas are identified, and channel belts are proposed more often there.

In addition, the impedance of a channel is drawn from a distribution which depends on how good that impedance would explain the residual in a randomly drawn trace in the area the channel passes through.

3. RESULTS

A true reservoir was generated with channel geometries large enough to be detectable for the seismic. Impedances were generated as continuous fields, with expectation value 6900 for the channels, and 7100 for the background. The standard deviation for both fields was 200, and the horizontal range was half the reservoir length. Vertically, a very short range was used. Computing the reflections, and convoluting them gave the true seismic amplitudes used.

Note that this seismic generating does not follow the assumption of constant impedance inside a channel, or in the background. It allows the background to have lower impedance than the channels in some areas, although on the average, the channel impedance is lower. In the model used here, this impedance variation can be seen as noise. Under the model assumptions, about 50% of the variance in the true seismic amplitudes could be regarded as noise, as it came from internal reflections inside a facies object.

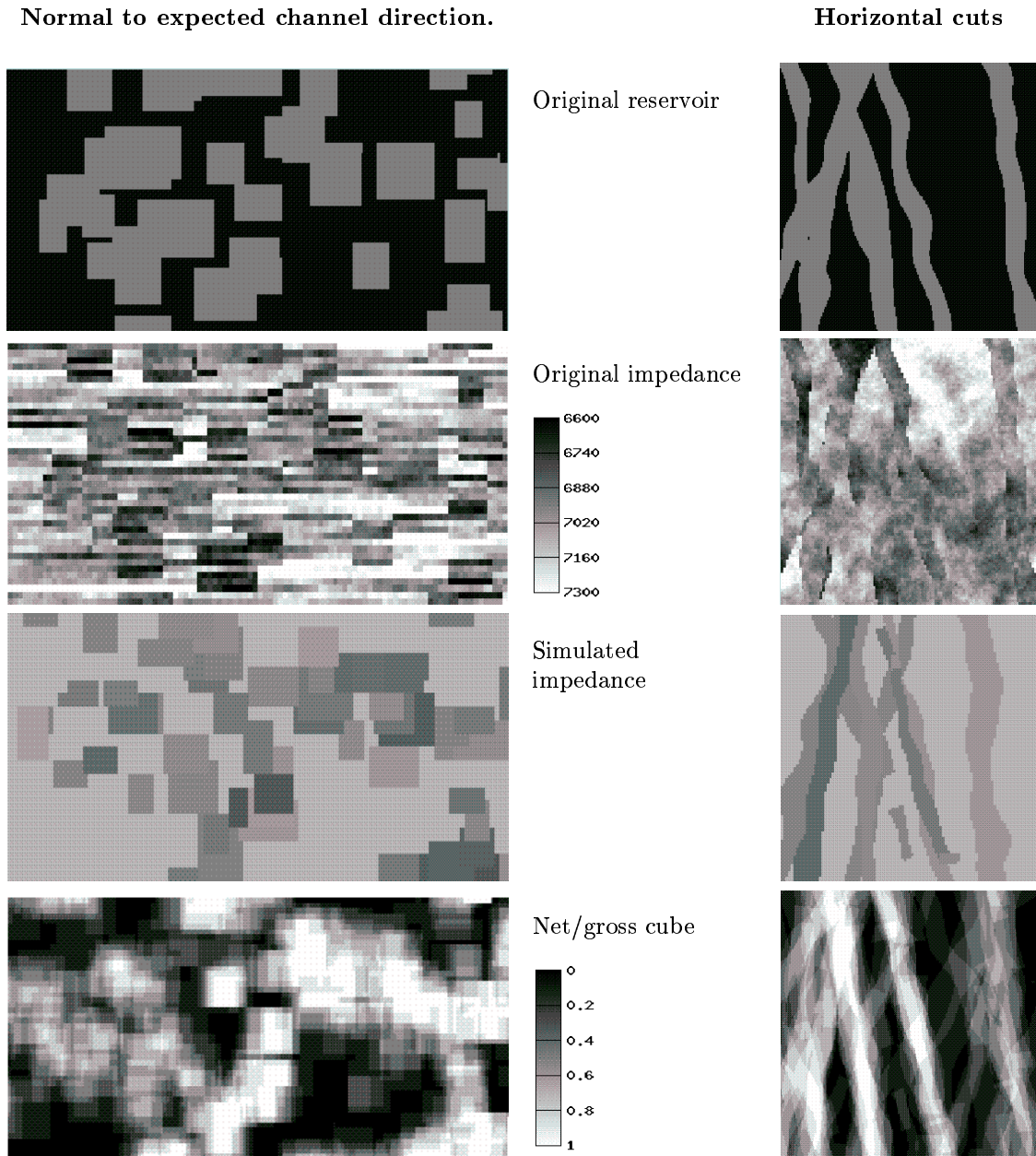**Normal to expected channel direction.**　　　　　　**Horizontal cuts**

FIGURE 2. Vertical (left column) and horizontal (right column) intersections in the middle of the reservoir. From top to bottom: Facies in original reservoir, the generated original impedance field, the simulated impedance field in one realization and the mean net/gross cube from 10 simulations.

A series of 10 realizations was then simulated conditioned on the generated seismic amplitudes. Cuts through the true and the first simulated reservoir are shown in Figure 2

together with average facies maps of the 10 simulations. The corresponding original, simulated and residual seismic amplitudes for the first simulation are shown in Figure 3.

(a)   Original amplitude

(b)   Simulated amplitude

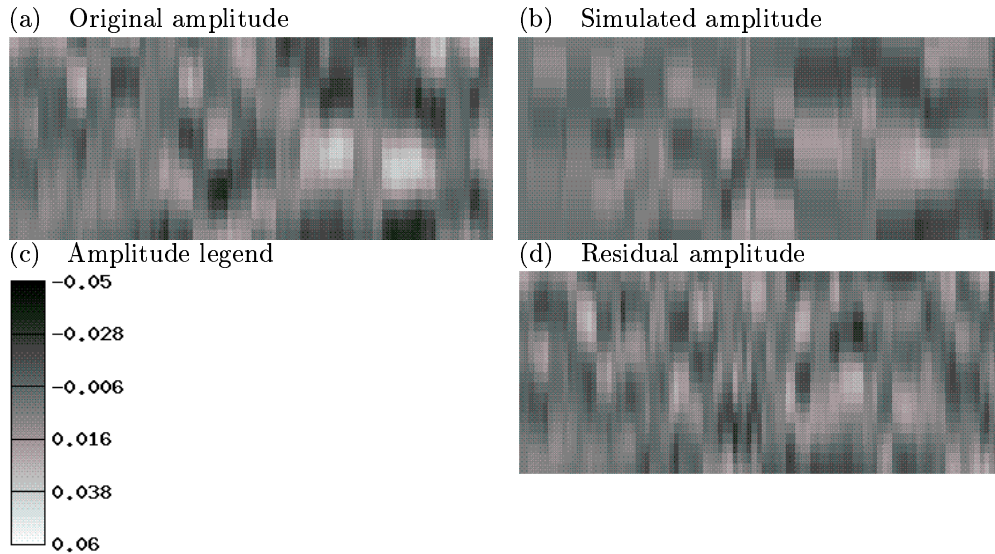(c)   Amplitude legend

(d)   Residual amplitude

FIGURE 3.   Amplitudes in a vertical cut through the middle of the reservoir normal to the expected channel direction.

The original impedance field does not give exact information about the channel location, and with the model having one impedance value for one channel object, it is not possible to reproduce a realistic impedance field. However, the average maps show that the channels are basically placed in the correct regions of the reservoir.

The residual amplitudes have less structure than both the original and the simulated amplitude field. This means that the main features of the original reservoir are contained in the simulated one. It is natural that the residual amplitudes have short horizontal range, as this occurs when a channels in the realization are located close to channels in the true reservoir. In all realizations, 50% of the variance was explained, which shows that the same amount of seismic information was used.

This conditioning has also been applied on a real data set. This data set was a poorer fit to the assumptions, mainly on three counts:

- The average impedance difference between channel and background was small, giving small reflections, sometimes with opposite signs.
- The modelled area consisted of several zones, to get a thicker volume for conditioning. However, this also gave significant variations in channel geometry, which the geometric model could not handle properly.
- There were trends in the variance distribution, which does not correspond to the assumption of a uniform noise variance.

Due to these phenomena, the percentage of variance that was explained by the synthetic seismic was down to 16%. Although this is only a third of what was achieved in the synthetic case, it still represents a significant reduction of the state space. Again, all realizations had the same variance in the noise, indicating convergence with respect to the seismic term, and that all seismic information that could be utilized in this model was utilized.

When the difference in impedance between channel and background is small, the uncertainty will increase, as the information content in the input data is smaller. This is a problem for all seismic conditioning models. The two other problems could be overcome by extending this model — making the channel geometry more flexible, and assuming that the noise is a given percentage of the variance locally would probably improve the conditioning.

4. CONCLUSION

The method showed promising results in the synthetic case, reproducing the original seismic amplitudes to the desired degree, and giving realizations with clear similarities to the original reservoir.

Although the performance on a real data set was much poorer, the conditioning still worked, even though the impedance contrast between facies was small, and the fit to model assumptions was bad.

5. ACKNOWLEDGEMENTS

References

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