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Dynamic Cluster Analysis for Updating Simulation Model Using Time-lapse Seismic

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SUMMARY

4D Seismic data analysis is well established for reservoir characterization and improving reservoir development. Usually 4D seismic interpretation results are used in history matching, but here there are still some arguable considerations regarding its interpretation as well as direct use in such a procedure. The method proposed here avoids ambiguity in seismic interpretation, and thus facilitates the history match. It is especially effective for baffles and barrier location (i.e. reservoir connectivity), and also the identification of fluid pathways in the reservoir.

Introduction

4D Seismic data analysis is well established for reservoir characterization and improving reservoir development. Usually 4D seismic interpretation results are used in history matching, but here there are still some arguable considerations regarding its interpretation as well as direct use in such a procedure. The method proposed here avoids ambiguity in seismic interpretation, and thus facilitates the history match. It is especially effective for baffles and barrier location (i.e. reservoir connectivity), and also the identification of fluid pathways in the reservoir.

Method and theory

The proposed method uses cluster analysis. This approach was first used by Tryon (1939), and encompasses a number of different classification algorithms. All these algorithms are used for the organization of observed data into meaningful sets or structures. A K-means clustering algorithm is utilized in this work, the method aims to partition number of observation (n) into k sets ($S = \{S_1, S_2 ..., S_k\}$), in such a way, that each observation belongs to the only cluster (set) with the nearest mean

$$\arg\min_{s} \sum_{i=1}^{k} \sum_{'x_j \in S_i} \left(x_j - \mu_i\right)^2$$

where μ_i is the mean of points in S_i. The proposed method is based on cluster analysis of multiply repeated 4D surveys. This consequence of this is that the simulation model grid is divided into clusters of cells with the same behaviour. Transmissibility between clusters is changed for matching seismic and production data. Thus, in our case, clusters are representative of reservoir volumes on the basis of the seismic signal similarity through time, where number of clusters *k* depends on available 4D surveys, but has a limit which can be easily determined. The cluster location, size and volume are constant for a particular number of 4D surveys analysed.

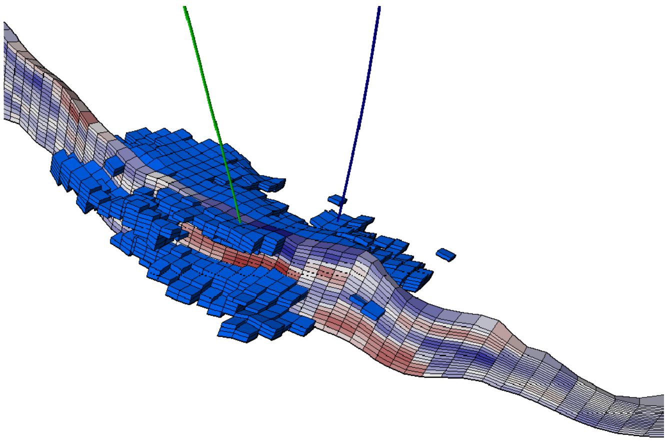

Figure 1. *Cluster representation overlapped with seismic data.*

Each cluster has it is unique characteristic curve. The number of type curves is limited by the number of seismic surveys and number of well types (injector/producer). Produced and injected volumes between surveys should be comparable and sufficient to be detectable by the seismic. A validation of this approach can be achieved using well data along with seismic. The presence of active wells is detectable by clusters. In fact – wells are sources for seismic amplitude changes and at the same time they are sources for saturation changes. Using multiple seismic surveys force us to use alternative time sequence- creation of difference maps, 3D grids or any other kind of data for all possible pairs of seismic surveys. Consider a pair of two wells: injector INJ and producer PROD. From the material balance point of view they have opposite signs: injector '+' (inject/add volume into reservoir) and producer is '-' (produce/withdraw from reservoir).

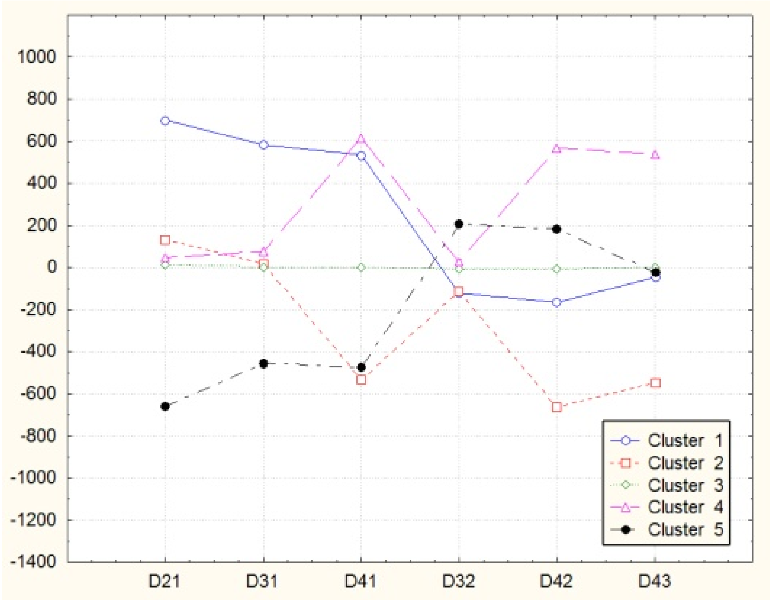

***Figure 2**. Cluster type curves. Y-axis- amplitude difference, X-axis- corresponding time step (D21= time between Monitor 1 and Baseline, D31= time between Monitor 2 and Baseline, D43= time between Monitor 3 and 2)*

That means that the plot reflects changes in cumulative volumes (injected or produced), and those for the injector will be symmetrical with respect to the producer if these wells have a hydrodynamic connection. The connection in this case can be verified by well testing and historical well data.

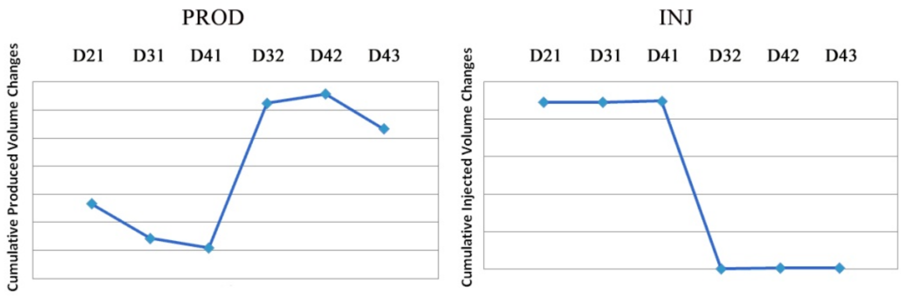

***Figure 3**. Well type curves.*

The slightly different shape of the type curves can be explained by the fact that INJ was closed just after few years of injection. The curves depicted on the previous figures reflect two clusters for the first time segment (BL-M1), cluster 1 and 5 (see *Figure 2*). That means that the largest changes of volume in the reservoir are between BL and M1. This is verified by the history data. INJ was closed just few months before the first monitor. PROD was opened during whole reservoir life, but if we compare produced volumes in the corresponding periods – obviously about 73% of production occurred in time step 1 (BL-M1). So, there are observed similarities between the well and seismic responses in *Figure 2* and *Figure 3* - which infers well connectivity with a particular cluster. This is a tie for the well and seismic domain. Each cluster type is an actual reservoir volume changed in a particular time segment (step) and we need $2(n-1)+1$ (where n is a number of surveys) clusters for full cluster characterization of the field. The factor of 2 is because there are two well types- injectors and producer, and the addition of 1 is for the 'non-active' cluster - which reflects shales or areas non involved in sweep process, so they can be infill drilling targets. Next, we know that clusters can be connected to the well, in most of the cases only one (or two) cluster has a connection with the wellbore- for the first time segment (BL-M1), the next cluster (M1-M2) is adjacent and connected to the first one, and so on. Thus we can see fluid pathways and understand the exact track of the well connections.

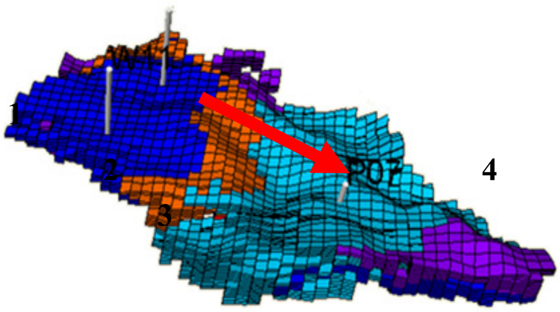

Figure 4. *Fluid pathways, synthetic example. Fluids move from cluster 1 (dark blue) through 2 (red) towards 3 (light blue) and 4 (purple). Red arrow reflects flow direction.*

Results of data application

The ultimate goal is updating the simulation model and following the workflow (*Figure 3*).

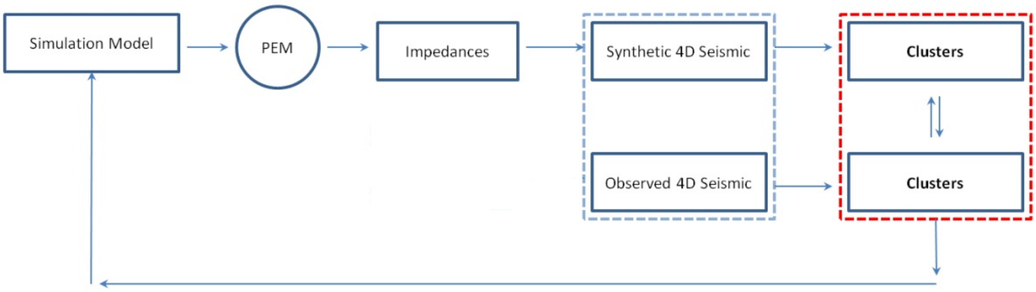

Figure 5. *Workflow used for model update.*

Similarity (in the 3D volume) of the clusters derived from the observed seismic and from the simulation model is used as a part of the misfit function as well as the difference in production history data and simulated one. The method is successfully applied to a North Sea field. The oilfield is a compartmentalized turbidite reservoir with a complex geology.

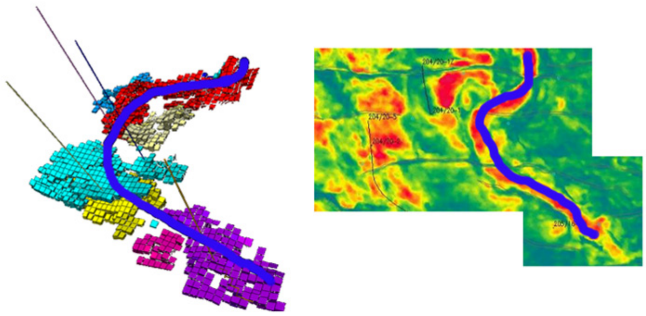

Figure 6. *Left* **-** *connected volumes from the clustering. Right - baseline survey response (Martin, K., and MacDonald, C., 2010). Compared with the geology – the clusters display the channels (blue curve), but with additional data about the flow character.*

Figure 7 represents the initial connectivity and also the updated one. Zero implies no connection and unity a very good connection correspondingly. This result is achieved just after the first iteration step - we determined 'non-active' cells in the model and set them to zero transmissibility for the fluids. The connectivity pattern is affected, so this results in a dramatic production match improvements.

Conclusions

Due to the nature of method, it takes into account of all the presented seismic surveys simultaneously, which dramatically increase the accuracy of the results. As was mentioned, it is very fast to implement. Due to direct use of the seismic data with the simulation model, the method reveals a capability for quantitative seismic understanding in the engineering domain, especially for inter-well connectivity and integrating results with well testing or the PLT.

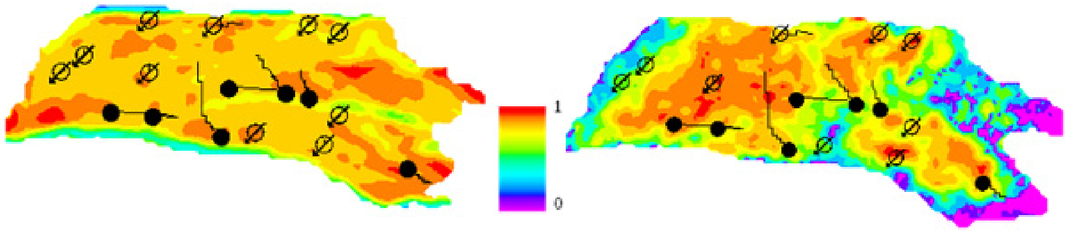

Figure 7. *Results. Initial connectivity (left) and updated connectivity (right)*

The seismic misfit is assessed also, and the observed improvement is about 22-23% (see Figure 8).

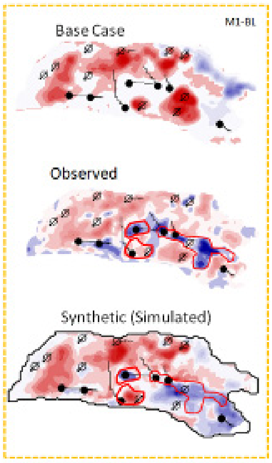

Figure 1 *Seismic comparison*

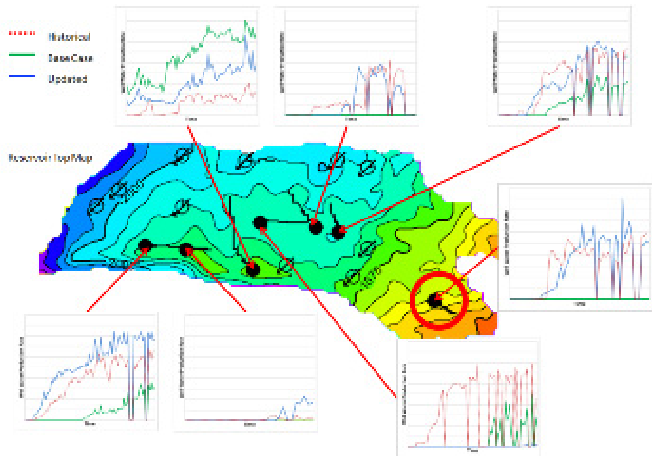

Figure 2 *Results. Production data matching. Red dotted line- historical data, green line- base case model, blue line- updated model.*

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