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Characterization of Compartmentalized Reservoirs with CO2 Injection Using a Level Set Method and Incorporating 4D Seismic

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The Earth has a very complex structure and it is impossible to determine from few injection and production data all the details of the reservoir. Many reservoirs are composed of different geological regions (lithofacies) which are separated by clearly defined interfaces or contain certain channel or barrier structures. Some of these interfaces can be determined by seismic analysis, but not all of them. Traditional history matching techniques are not able to resolve these interfaces due to the way these tools are constructed. Typically an inverse problem is solved for determining pixel-values (voxel-values in 3D applications) of geophysical parameters (e.g. permeability) inside the reservoir which minimize, when plugged into a reservoir simulator, the mismatch between simulated and actual production data in some sense.

On the other hand, the simulation of CO2 injection into depleted hydrocarbon reservoirs can be understood as an Enhanced Oil Recovery technique that involves physical and chemical processes and different kind of data, for example, seismic, petrophysical, pressure, production data that should be integrated to reduce the uncertainty of the characterized reservoir. An important aspect of this process is the correct characterization of permeability distributions in a reservoir with more than one lithology. Here, the presence of channels will constrain the movement of the CO2 trough the reservoir. Many techniques have been developed which recover either the interfaces or a smoothly varying profile in the individual regions, but not both of them. Our group has developed recently a novel method for modelling and reconstructing geological shapes in reservoirs from production data. This method is based on a level set representation of the shapes. In our previous work [1,2] we recover simultaneously from the same data the shapes of the different geological regions and variations of the permeability distribution in each of these regions. Only one forward model simulation and a corresponding gradient estimator are necessary for calculating both updates of a water flooding process, In our previous publications we presented numerical results for realistic two-dimensional situations. In this work we extend our previous method for recovering the shapes of different geological regions and variations of internal permeability distributions in each of these regions to three-dimensional reservoirs which show sharp discontinuities in the permeability values between these lithofacies. This generalization enables us to reconstruct geological shapes and properties in stratigraphic compartmentalized 3D reservoirs with CO2 injection using the level set method, based on pressure and production data. In this work we use a compositional numerical simulation model in order to represent in a sophisticated and realistic manner the interaction between the fluids of the reservoir and the CO2 being injected. In each step of our new reconstruction technique, the production data will be used in order to calculate an update for the shape of the lithofacies using

the level set method. Additionally, following the current general guidelines of oil industry focusing on the integration of multidisciplinary aspects into the workflow of reservoir characterization, the prior information integrated in our approach incorporates the application of a permeability estimation from production and time lapse seismic data [3] in order to get an initial permeability map of the reservoir consistent with the available 4D seismic information. This step is used in our strategy for constraining ('conditioning') the model estimation or, alternatively, for providing us with an optimal initial guess for the search. In the figure 1 is displayed the general workflow of our integrated and multidisciplinary methodology. Initially we use the prior geological model, petrophysical data (specifically permeability versus porosity trend), the time lapse seismic information and the production data in order to generate a new initial guess of the reservoir simulation model. Later we carry out the history matching using a compositional simulator to estimate the gradients to be used by the level set technique for finding the channel distribution throughout the reservoir.

Summarizing, we present a new approach for CO2 injection simulation which is able to reconstruct two lithofacies of complicated shapes and the corresponding permeability distributions simultaneously from these production and CO2 injection data considering a synthetic but realistic compositional model and making use of the available 4D seismic information. Moreover, we describe techniques for testing the existence and characteristic features of certain geometrical structures (such as channels or barriers) inside the reservoir by suitable topological perturbations of the describing level set functions. Numerical results are presented which demonstrate the performance of our novel scheme for a variety of simulated but realistic situations which are of importance in reservoir engineering applications. This novel reservoir characterization technique directly provides structured profiles of physical parameters (here permeability) from production data without the need of any segmentation post-processing techniques.

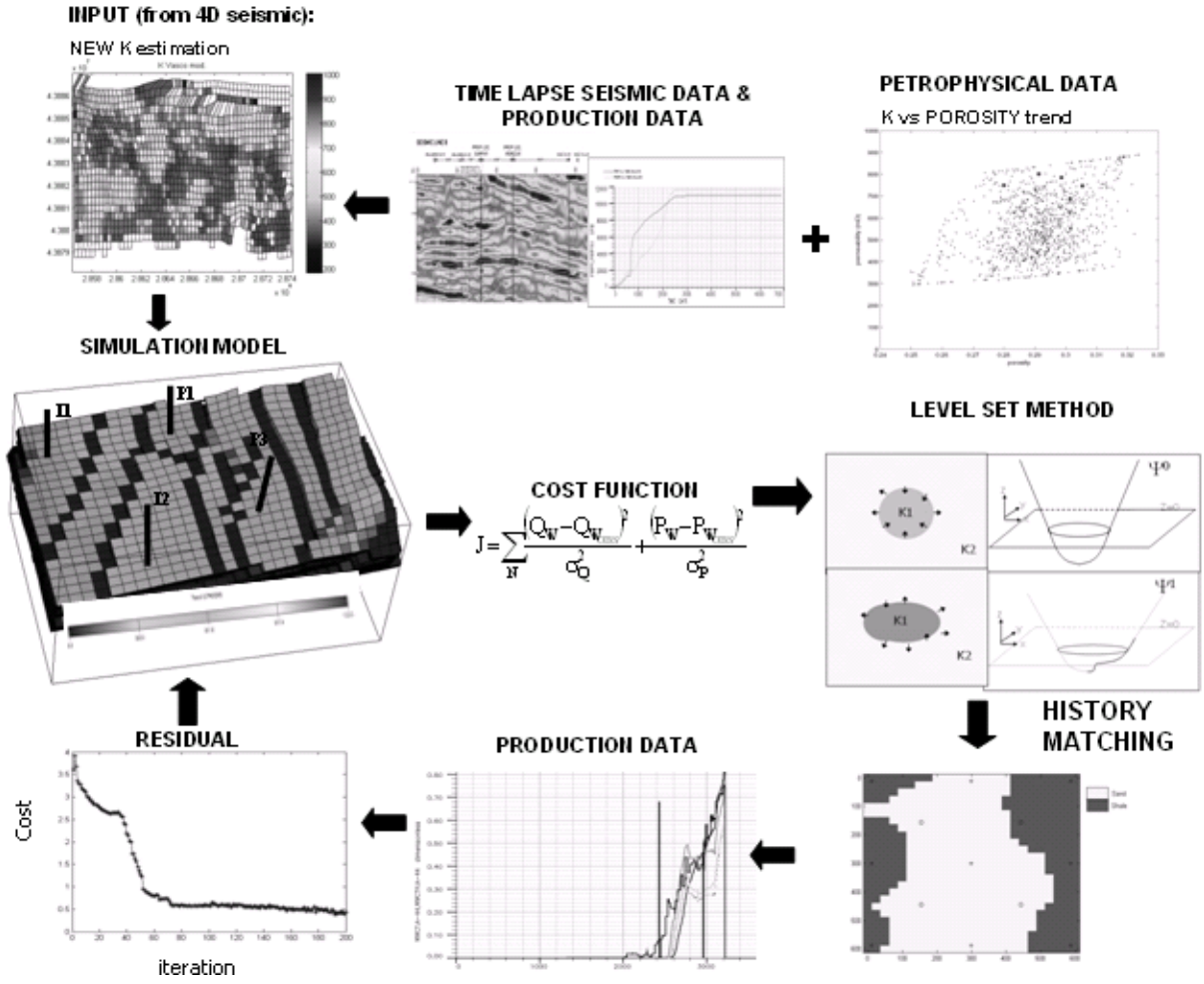

Figure 1 - Workflow. Characterization of compartmentalized reservoirs with CO2 injection using the level set method and 4D seismic.

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