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A New Shortcut Workflow in Flexible Reservoir Modeling: Introducing Structural Features without Re-Gridding

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Abstract

Current reservoir modeling workflows are very rigid, since any modification to the understanding of the underlying structural model often requires a complete regeneration of the reservoir grid, with the associated costs, delays and incompatibilities with past calculations. We propose a novel workflow for structural features modeling, allowing the introduction of faults and other structural and non-structural features in any kind of simulation grid without modifying it. A new tool, capable of implementing the proposed workflow, is presented along with several real-world case studies that prove the advantages of the new workflow.

Introduction

The modeling of a hydrocarbons reservoir (Mallet 2008) is a multi-scale and multidisciplinary process that usually involves several months for a complete loop from seismic interpretation to reservoir simulation analysis. One crucial moment in the life of a reservoir model is the creation of its reservoir simulation grid. The latter encodes the so called structural model, (see Figure 1), a set of surfaces representing interfaces between different geological features. These features are typically the faults of the model, and they can contain important geological properties such as the fault throw, (see Figure 5), the shale gouge ratio, etc. A given grid cell can only belong to one side of each of these surfaces, which generates geometrical "tension" on the grid. Once the reservoir simulation grid is created, every aspect of the simulation depends on it.

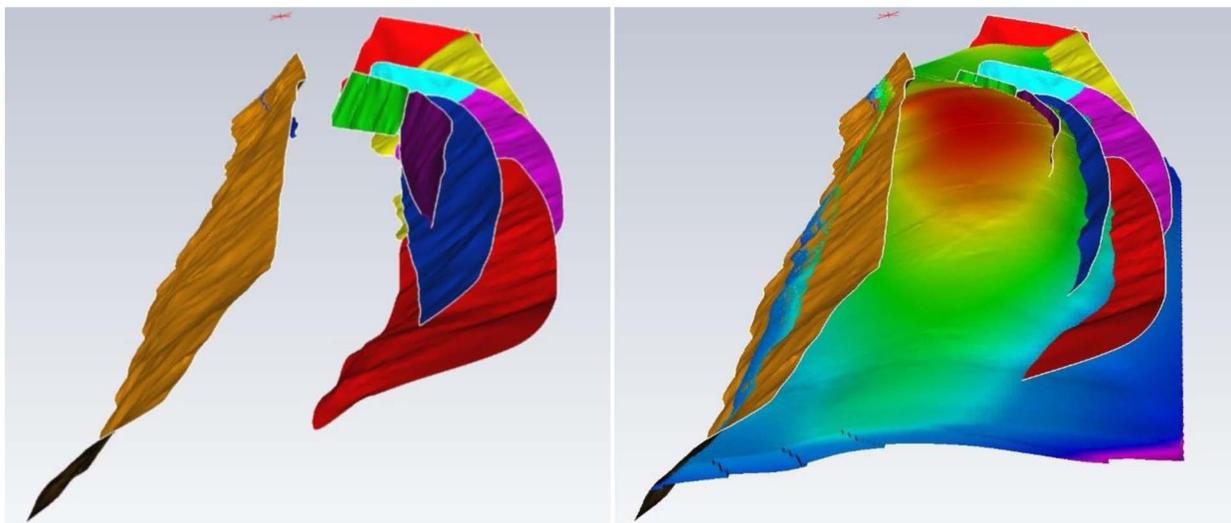


Figure 1—Left, the seismic faults of a structural model. Right, the faults and related reservoir grid.

A team of dedicated specialist paints the needed petrophysical properties and fluid saturations on the grid, computes the well-to-cell connection factors, etc. Several weeks or even months are spent in building and quality checking the reservoir simulation model that is completely based on the cell division of the space determined by the reservoir grid. Simulations are then run to be compared with actual data, when available, or for conceptual design of the production methods and structures. In other occasions the model preexists and new production data is acquired. These simulations and comparisons may sometimes hint fundamental flaws in our simulation model. For instance, the existence of an unseen or underestimated fault that was not included in the reservoir structural model, or the need to model differently the flow across a fault between different flow panels as a result of ignoring a fault relay. In these cases, the reservoir engineer has to make a decision. The engineer can decide to "live with the issue," leaving a wrong model for the rest of the field's life, but retaining compatibility with previous simulations. Another option is to perform painful manual modifications to reservoir properties to mimic the missing feature, but these are extremely costly and the result is often non-geological and most likely inconsistent with future evolutions of the model. Finally, it could be demanded to the seismic interpretation team to add the missing fault to the structural model. The engineer knows that this may require many steps: start by picking and cleaning the fault surface to then stitch it to the old structural model and rebuild a new version of the reservoir on it. The geometry and number of cells will change and the whole painting and quality check workflow has to be re-done. Expected timelines will be delayed, the budget will grow and some development decisions will have to wait for the new simulations. On top of this, since the concept of grid independence (Patankar 1980) is essentially unexplored in oil and gas industry, the previous results will not be strictly comparable to the new ones. Consequently, there is loss of historical consistency and it is needed to repeat former simulations to achieve the tuning of the new model. If all this was not enough to discourage and freeze the engineer, we should also consider the level of confidence that those changes will actually be enough to solve the problems. If only some quick test simulations were possible before launching a full regridding... This nightmare happened, happens and will continue to happen, but possibly not twice to the same reservoir engineer. In future projects the engineer will take great care to ensure that every little trace of a fault is included in the first version of the structural model. In this way we can always set transmissibility multipliers to 1 and, the facto, remove them from the actual simulation if needed, but we pay a heavy price for this strategy. Models become humongous and very difficult to manage with often over 200 faults, see Figure 2.

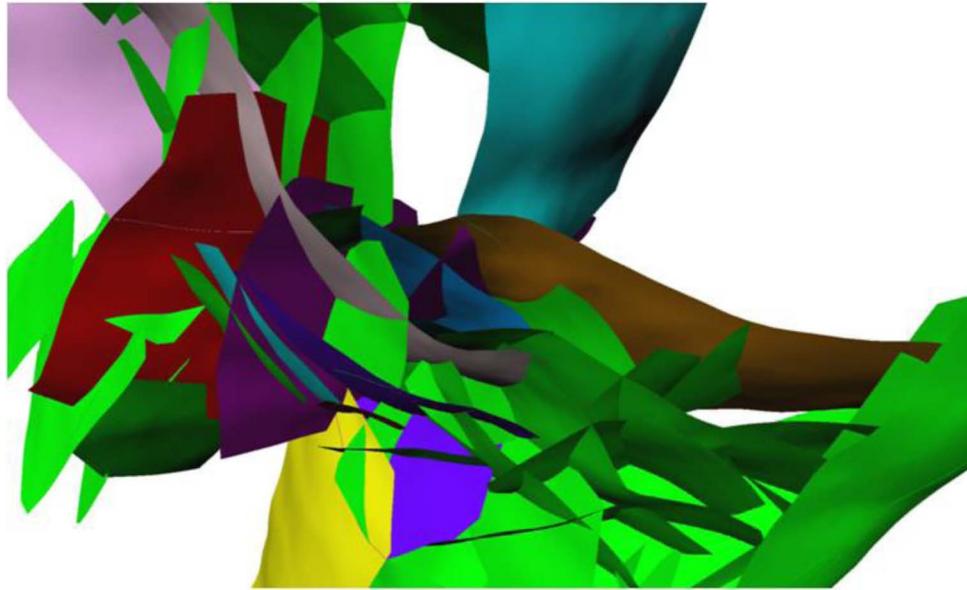


Figure 2—Example of overcrowded real structural model.

A reservoir grid built around such a complex structural model has to meet too many geometrical constraints like minimum number of cells between consecutive faults, different lining up of faults, dipping and intersecting faults that produce Y or "lambda" structures... Pillar faults are of course of the table at this point and stair-step faults or unstructured grids take over. Flow simulation in a reservoir grid distorted by so many faults is often badly conditioned because of the loss of k-orthogonality, see (Jackson, et al., 2013) or (Wu & Parashkevov, 2009). In addition, problems with time step due to volume disproportion in consecutive cells or cells with over 40 NNC's are also found.

In the following we present a new tool capable of introducing surfaces implicitly in a reservoir grid, whatever its kind. The surface could be picked from seismic or synthetically drawn and it could represent any geological feature like a fault, an unconformity or the external envelope of a body. This tool allows a large family of new fast workflows in reservoir modeling and allows a so far unknown flexibility in structural conceptual modeling. We present a selection amongst these new workflows that were already applied in production projects.

General new workflow and tool capabilities

The objective of the new tool is to communicate directly with the simulator by modifying the simulation deck so that the new surface is taken into account as a flow modifier while simulating. The surface is represented in the grid as a set of intersected cell-to-cell connections, hereafter a *connection set*. This representation language can be directly understood by the most widely used simulators and allows to easily adjusting transmissibility multipliers on the newly introduced feature, both as a global value on the whole surface, or as a connection-dependent function.

The intersecting algorithm, which is described in more detail in (Frambati & Rodriguez-Martinez, 2017), consists of an alternating propagation process that follows both the topology of the surface, represented as a triangulated surface, and the topology of the reservoir grid. This process requires a first step consisting of a "seeding" in which we find a first cell to start the search, complexity $O(n \log n)$, followed by an alternating propagation over the grid and the triangulated surface, complexity $O(k)$, where n is the number of cells in the grid and k is the number of cell couples that represent the surface in the grid. With real-world data, the computational time is in the order of a couple of hours in a regular professional station for a couple hundred surfaces intersected with a faulted reservoir grid of 20 million cells. The interest of this tool becomes evident

when this time is compared with the full regriding workflow to introduce any modification to the structural model.

The output of this algorithm is a set of couples of cells such that their centers rest on different sides of the introduced surface. The fault side on which every cell lies is also determined. This naturally leads to a grid property colouring differently the cells on opposite sides of the original surface. Also, a new triangulated surface is built with the polygons resulting of intersecting the opposed faces of each couple of cells selected in the intersection process. Such surface is always water tight and most importantly; it represents exactly the cell-to-cell connections in the reservoir grid that will be affected by the newly introduced feature, see Figure 3.

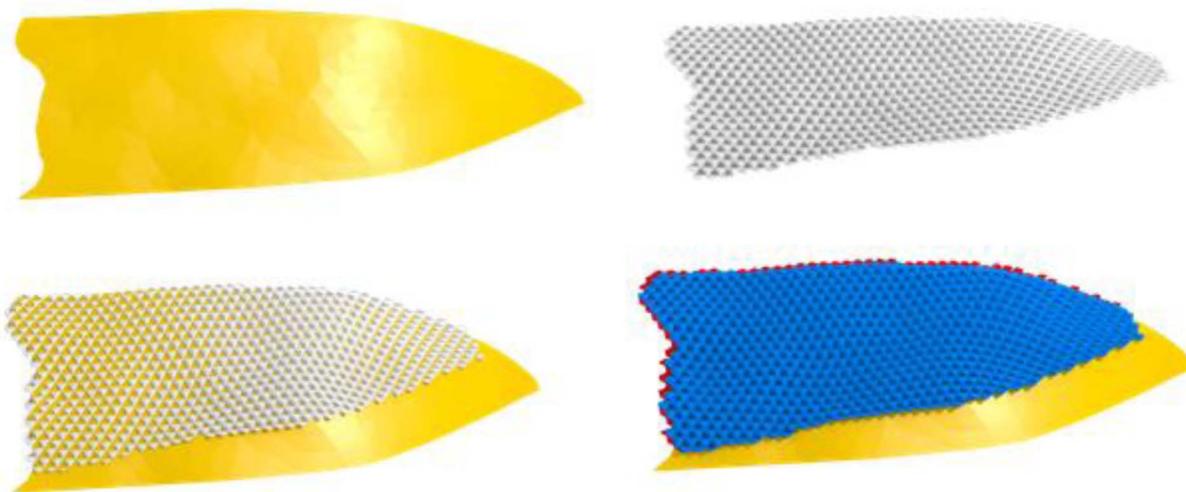


Figure 3—Top left: Triangulated surface of a fault. Top right: Associated connection set surface. Bottom left: Superposition of fault surface and connection set surface for placement control. Bottom right: "left" and "right" regions, coloured in blue and red, displayed around the fault surface.

Along with the visual quality control reservoir property and 3D surface, the tool also outputs include files formatted to be read by most common simulators in the market. These *include* files allow, by means of a simple text editor or a dedicated tool also already available, setting transmissibility multipliers on the connection sets of each of the features introduced. Transmissibilities on the intersection between connection sets of different features (cell-to-cell connections intersected by several surfaces) are automatically singled out and can be handled on the fly with simple rules of the kind: "most restrictive," "less restrictive," "harmonic average," etc.

Using this tool, we can also transfer properties from the surface, such as throw or SGR, to its connection set representation. In turn, this allows a post process in which the transmissibility multiplier of each cell-to-cell connection is functionally determined from properties in the grid and each cell-to-cell connection.

Use cases

First we present the two most basic use cases of the tool: introducing an underestimated fault and splitting another fault, both in the same reservoir simulation model that had already been used for some time. The model contains more than 150 faults and its reservoir grid has more than 18 million active cells. The complete rebuild of such model would take months of work by a dedicated team, whereas the new workflow only took a couple of days including initial quality control of the data, computation of the connection set and post process quality check before returning the results to the production team.

In the underestimated fault case, a fault was observed in the seismic data but it was not deemed important for the simulation due to its very small throw and consequently it was not included in the structural model

used to build the reservoir grid. However, during history matching, it was impossible to correctly match the pressure profile for a well going directly through the fault. Including the fault in the grid was not feasible since this would have required a costly regridding and loss of any possibility of comparison with older simulations. Using the proposed workflow, the fault was included implicitly (Figure 4, right), leading to an improved pressure matching on the problematic well, without impacting the matching in other wells. Since the reservoir grid was not modified, the whole operation took only a few hours.

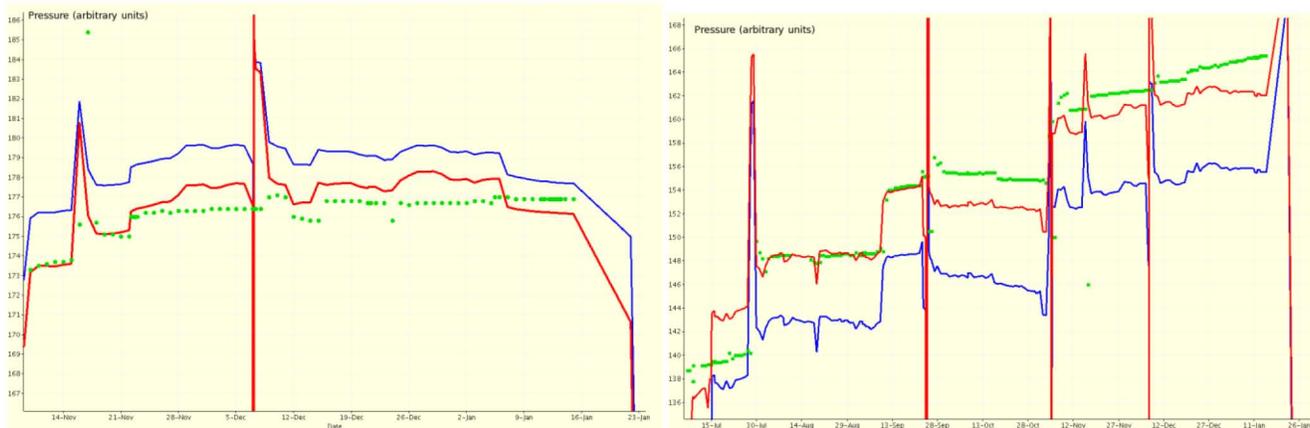


Figure 4—Comparison between the pressure histories at wells near a fault splitted (left) and added (right) with the proposed workflow. Historic data is in green, baseline simulation results are in blue, and the simulation results after the modification by the workflow are in red.

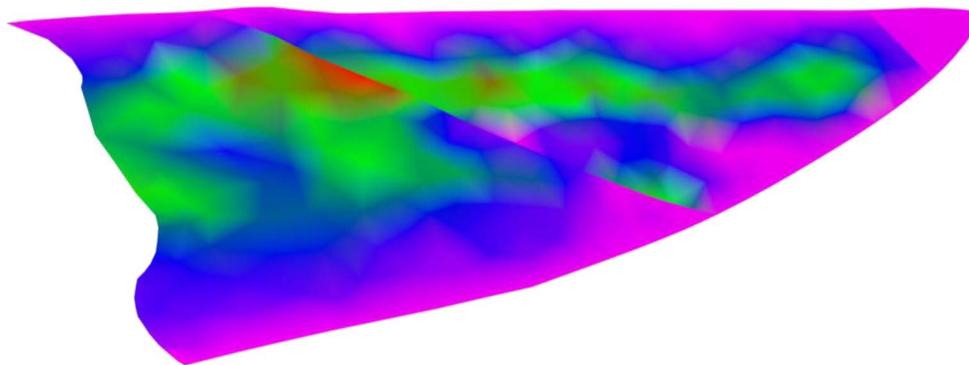


Figure 5—Fault triangulated surface coloured by interpolation of throw values on its vertices.

In the split fault case, two faults were simplified into one in the original structural model, and a single transmissibility was assigned to them. As a result, during history matching, no single transmissibility multiplier was able to match historic and simulated pressure for a well situated in the vicinity of the fault. In order to obtain a more consistent geological profile and simulate the relay missing from the structural model between the faults, the fault surface was split and the workflow was run. The merged fault was implicitly replaced by the two newly-created faults in the model, without need for regridding. As it can be seen in Figure 4, left, a subsequent history matching was able to better match the pressure history at the well, without impacting the matching for all the other wells. In the matched simulation, transmissibilities for the two faults differed by two orders of magnitude, indicating that the role played by the relay was not minor.

The following use case is, so far, the most advanced new workflow performed for a production project with the tool presented here. In this case the geological environment is dominated by several deep listric faults with sever change in dipping with depth. Tests and historical production data on the field confirmed the dependence of fault's transmissibility on local fault throw, but the size and number of the objects made it impossible to adjust transmissibilities by hand. Instead, the proposed workflow found the connection

sets corresponding to each fault and on-the-fly transferred the fault throw property from the vertices of the fault triangulated surfaces to the corresponding connections. The transfer of property values is carefully performed with differential treatments for intensive and extensive properties. The computation itself consists on a linear interpolation from the surface vertices to the polygons intersected within each reservoir grid cell, followed by a barycentric averaging over all polygons within each intersected cell of the reservoir grid. A simple post process set a computed transmissibility on each connection as a function of its fault throw. In [Figure 5](#) we see the fault throw property and its large variability on the triangulated surface that represents a fault in this simulation model. The footprint of other faults intersecting the one presented is clearly visible on the fault throw property in [Figure 5](#). In [Figure 6](#) we see the connection set surface coloured by its induced fault throw property. It is remarkable that all distinctive features of the distribution of the fault throw values on the original surface are still visible, including discontinuities due to intersecting faults. As a final test, in [Figure 7](#) we see the superposition of both previous surfaces with a reassuring resemblance between them.

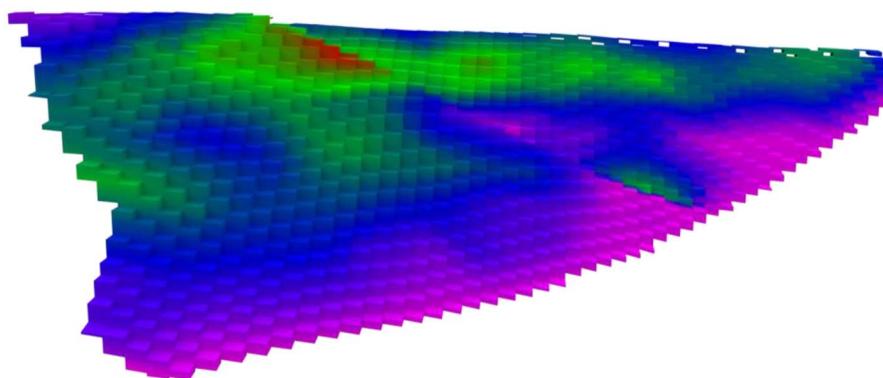


Figure 6—Connection set surface associated with the fault surface in [Figure 4](#) coloured by the fault throw property.

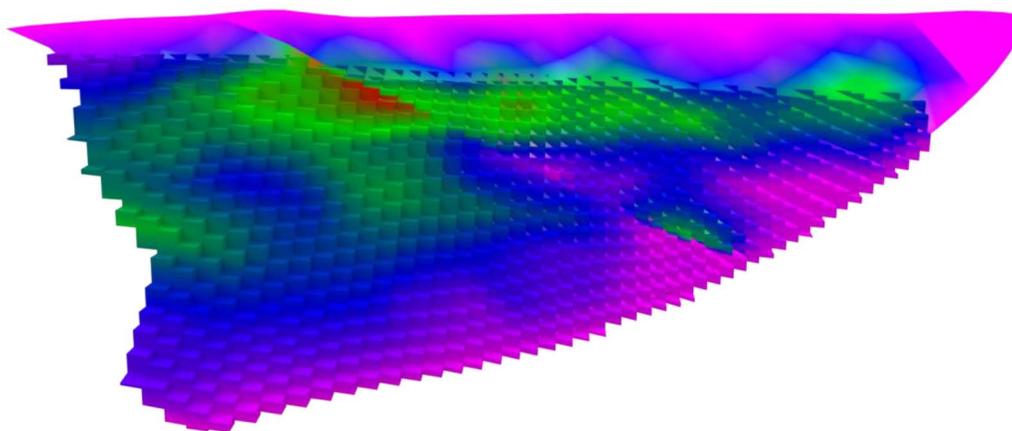


Figure 7—Superposition of the fault and the connection set surfaces both colour by fault throw to quality check the transference of property values and positioning of the connection set surface.

This object has been introduced already in simulations with initial success, but the production studies are still ongoing, therefore final results are not available yet.

The last example of application of the tool is on a synthetic model. Two faults and a channel segment have been drawn in 3D, [Figure 8](#) top left to then embed them in a synthetic reservoir grid, [Figure 8](#) top right. The workflow is then used to extract their corresponding connection sets, [Figure 8](#) bottom left. In order to test the water tightness of the channel connection set, its transmissibility multiplier is set to 0 in the simulation deck. The results of an injector/producer simulation are presented in [Figure 8](#) bottom right, with a very satisfactory final pressure distribution.

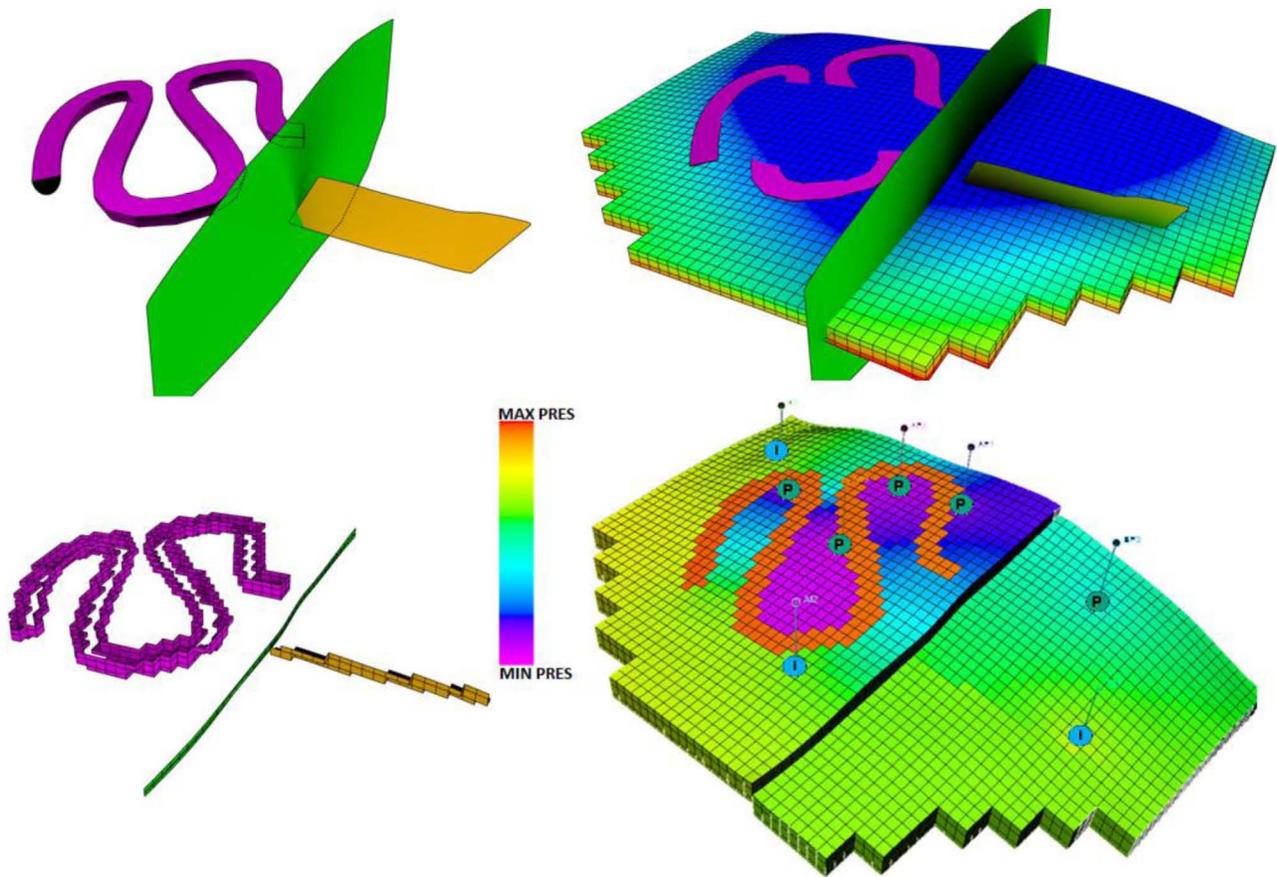


Figure 8—Top left: Synthetic channel and fault surfaces. Top right: Synthetic surfaces embedded in a reservoir simulation grid. Bottom left: Connection set surfaces resulting of the surface-grid intersection. Bottom right: Pressure property after injection/production simulation with transmissibility multiplier 0 on the channel connection set.

Conclusions

The tool presented finds the set of cell-to-cell connections in a reservoir simulation grid intersected by a triangulated surface. For large projects this computation is performed in a few hours with independence of the type of reservoir grid: structured, unstructured, with pillar or stair step structure, etc. All that is required from the reservoir grid is an application programming interface to navigate its cell to cell topology. The triangulated surface could be exported by any 3D drawing software as long as it is in a standard format.

This tool also allows the introduction of faults, horizons, channels, salt bodies or any other geological feature as an interface in the reservoir simulation model and allows an easy control of the transmissibility through them. The tool would also accept non geological surfaces as input for the computations, opening the door to fast conceptual designs of volume partitioning or testing the existence of features invisible in the seismic but visible in production or DST data. This freedom enables many different workflows that were not realistic before. For instance, it makes possible the on-the-fly introduction of faults that were underestimated or not seen while building the structural model, the possibility of performing an agile and fast conceptual analysis at very early exploration, as well as splitting/relocating/stitching faults or screening uncertainty about faults' relay size.

In each of the case studies that we present, the complete workflow took only a few days, including processing and input/output data quality control. This should be compared with the current approaches that demand full re-gridding, entailing months of delay and incompatibility with previous simulations, or inelegant workarounds that would represent a burden in subsequent manipulations of the model, which can very well be the rest of the field's operational life.

Advanced use of the tool allows the transfer of properties on the vertices of the triangulate surface to the out coming connection set. Therefore, we can assign a different transmissibility multiplier to each connection within the connection set associated to a feature. These multipliers could be the results of a computation involving properties on the surface itself (such as fault throw or shale gouge ratio, for example) mixed with properties in the intersected reservoir grid cells.

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