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# From Smooth to Stair-Step: Gridding Geological Features and Their Properties, An Integrated Approach in the Simage-CIG Geoscience Platform.

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## Summary

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We present a novel tool that was recently introduced in the Total's Integrated Geoscience Platform, Simage-CIG. This tool allows reservoir engineers to introduce and manage geological features and their properties in reservoir grid connections, and using them to set transmissibility multipliers for the Eclipse and Intersect simulators. Properties on surfaces can be used to define position-dependent multipliers in the case of strong spatial variation of flow-impacting properties. The tool was validated in synthetic as well as real cases, of which one is presented in this paper.



## Introduction and motivation

The geological context that exploration and production teams routinely have to deal with is becoming more and more challenging. Deep offshore, foothills and highly fractured reservoirs are now the bread and butter of hydrocarbon exploration, while seismic campaigns provide interpreters with increasingly detailed data, allowing for hundreds of small features to be introduced in geological models, pushing their complexity. The need to incorporate this vast amount of information into reservoir grids, whose geometry is highly constrained by current simulators' requirements (see Wu and Parashkevov (2009)), asks for tools to translate geological features into grid features while retaining all the important characteristics of the original structural and sedimentary models. Some approaches, such as PEBI (Melichard et al. (2003)) or unstructured (Jackson et al. (2013)) grids, can produce models of higher geological complexity without increasing the size of the simulation grid, by adapting the geometry of the grid cells to the local geological environment. However, these approaches require a profound rethinking of the numerical models used in simulators, and their widespread use in production projects will require a potentially long period of adaptation. More common approaches, such as pillar grids, introduce deformations and explicit discontinuities in the simulation grid. These methods allow a good control on the geometric quality of the grid but are very restrictive when it comes to common geological features like Y-faults. These methods also introduce non-neighbour connections (NNCs) between cells that can potentially affect simulation performance (see for example Hoffman et al. (2008) or Gringarten et al. (2008)). This variety of different approaches proves that handling such complex structures is a hard task, which can be particularly costly and burdensome for oil companies, occupying many expert resources for long periods and potentially delaying production. This is the case, for example, when a modification to the model is required due to new evidence coming from production data (e.g., adding a previously unknown feature or introducing a hole in a fault to simulate a relay). Another time-consuming procedure is history matching, which requires the modification of the transmissibilities defined on a set of faults in order to match simulator results with historical production data. Setting transmissibility modifiers requires a tool that can determine the cell connections intersected by a given surface. A transfer of intensive and extensive properties from the surface to the cell connections may also be required in the case of large spatial variability of flow-affecting fault properties such as throw, usually maximal at the center and zero at the boundaries, volume of shale or shale gouge ratio. Production teams in Total S.A. are routinely confronted to these same challenges, and answering them is one of the goals of the Sismage-CIG (Integrated Geoscience Suite) team of Total S.A.. To this end we have developed methods and implemented tools for the positioning of arbitrary surfaces and extraction of their properties into an existing reservoir simulation grid. The purpose of this paper is to present the method and application results obtained in production projects. The methods, workflows and algorithms employed are patent pending, but the authors feel that presenting a use case can be illuminating.

## Method

One of the starting points for the creation of a reservoir simulation grid is a set of surfaces representing features such as faults, bodies or horizons, along with some properties possibly defined on them. Often, these surfaces will be the result of structural modelling, and will thus have been co-refined and cleaned in order to form a watertight model, a required step in order to obtain a clean reservoir model. These surfaces are often described in terms of discrete elements, typically triangles or quadrilaterals, and properties are also often present on them, being defined on their points or their faces. The transfer of geological feature properties into the reservoir grid is achieved by the following steps: first, the cell connections crossed by the surface are determined, and surface properties are transferred from the surface to the cell connections. Secondly, a description of these connection properties is exported in a language comprehensible to reservoir simulators. Transmissibilities on the connections are then modified by reservoir engineers, either on whole faults at a time, or in a more refined way, connection-by-connection.

As discussed above, the first step of the method is the positioning of the geological surfaces within the reservoir grid. The representation of surfaces, and general continuous objects, in a grid-like discrete geometry (*voxelization*) is a well-studied problem. Some methods exist in the literature to perform this task. However, these methods often fail to take into account some characteristics that are found in today's

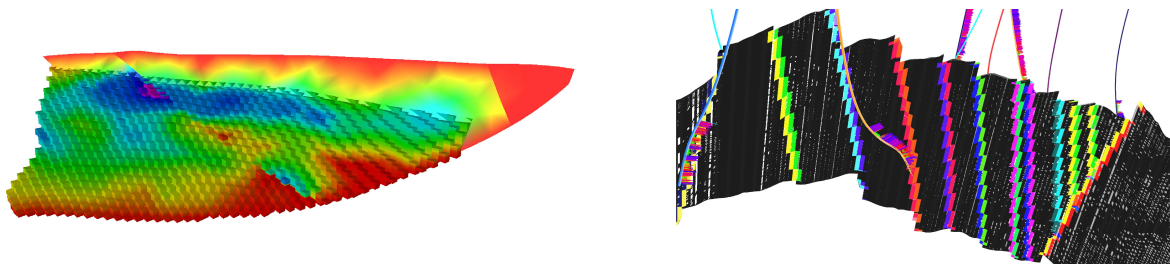


reservoir grids, such as non-neighbour connections. More general algorithms, such as that presented in Zomorodian and Edelsbrunner (2002), often present a prohibitive computational burden for reservoir applications, which routinely involve  $\sim 10^7$  cells and hundreds of faults, with  $\sim 10^6$  surface elements in total. Moreover, these algorithms are often tuned for cases in which the two intersecting objects are of comparable dimensionality (e.g., two surfaces), and the number of reported intersections grows linearly with the total number of elements in either object. For these reasons, no state-of-the-art approach seemed appropriate for the Sismage-CIG needs, which motivated the development of a novel proprietary approach. This method is general enough to cope with all the peculiarities of *all reservoir simulation grids*, structured or unstructured, potentially containing non-neighbour connections. The algorithm used to achieve this goal cannot be discussed in detail in the present paper, since it will take us too far from applications, and because it is patent pending. A significant speedup is obtained by using this proprietary method, achieving a computational time which is substantially independent from grid size, and mainly driven by the number of reported connections. This algorithm also allows to quickly determine all pairs of grid cell and surface element that intersect, which then allows in a straightforward way to transfer properties from the surface to the grid connections.

Once all cell connections have been determined, reservoir engineers can use this result to modify the effect of geological features such as faults and erosions in the reservoir simulation. In order to achieve this control, it is necessary to be able to modify transmissibilities on connections during the simulation. Quite generally, this is achieved by applying a suitable *multiplier* to the transmissibilities which were pre-computed by the simulator on the basis of geometry and NTG alone. This multiplication factor may be computed on the basis of further geological insight or experimental data gathered during the field's operational life. Alternatively, many different values may be tried in a screening process (history matching). Multipliers can be set in different ways depending on the reservoir simulator to be used. For example, the Intersect simulator (Schlumberger (2015b)), currently under active development, is able to understand connections directly in an abstract way, allowing the reservoir engineer to flexibly modify transmissibilities based on features, properties, or other criteria. Each cell connection is described individually, independently of its nature (logical connection, non-neighbour connection, connection between unstructured grid cells, etc.). However the Eclipse simulator (Schlumberger (2015a)) still enjoys widespread adoption, being it a tool well-known to production teams. Consequently, the authors felt that it was imperative to find a way for Eclipse users to handle multipliers in a similar way. Eclipse relies on a variety of methods to set transmissibilities for reservoir simulations. A multiplier can be independently set on each connection using one of the `MULTIPLY TRANX/Y/Z` or `EDITNNC` keywords, according to the nature of the connection. This approach can be used when the transmissibility depends on some of the properties defined on connections, since a different value can be set for each connection, reflecting the variability of the underlying properties. Multiplier values can for example be determined by applying a suitable empirical function to position-dependent properties such as throw or shale gouge ratio. An example of fault represented in the reservoir grid is shown in Figure 1, left. Only the faces between the two regions representing the fault in Eclipse are shown. The *stair-step* geometry of the fault, induced by the grid, is apparent. The fault throw on the fault surface, as well as its representation in the grid, is also shown. The correspondence between the two is striking, and shows the satisfactory level of granularity with which the multipliers can be manipulated. For more common use cases, in which a single multiplier is defined for each geological feature, this process is however awkward and unnecessarily cumbersome. Another approach, based on the `MULTNUM` and `MULTREGT` keywords, can be used to simplify the task. With this approach, a number of regions is defined on the grid. Each feature surface is then defined by at least two regions, representing the two sides of the surface (such as the hanging wall and the foot wall in the case of a fault). These regions, however, are only defined in the close proximity of the surface, and do not extend away from it, thus making regions belonging to different features essentially independent, and vastly reducing the combinatorial complexity of the problem. This approach compares favourably to other similar methods which are also based on regions. The *fault block* approach, for example, also starts by defining every fault as two regions, each representing a side of the fault. These regions, however, extend far away from the fault surface, so when more faults are added, all possible combination of fault sides must be taken into account, thus leading to a combinatorially increasing number of regions. This makes the fault block method highly impractical when a large number of faults,  $\sim 100$ , is present. The method proposed in the present paper does not suffer from this drawback, since regions are only defined in close proximity to the surface. Whenever several surfaces share the same cell connection,



some additional regions are indeed introduced to represent the intersection of the surfaces, but this only occurs where the surfaces representing the geological features actually intersect, and the number of such intersections between features is not in general combinatorial: only neighbouring features can touch. At the end of the process, every feature is represented by a limited set of connections between regions. An example of a reservoir grid in which these regions have been defined is shown in Figure 1, right. The resulting set of regions is usually small enough to be directly handled by the reservoir engineer. However, in order to simplify the engineer's task, the process of recovering all region connections belonging to a given feature has been automated in Sismage-CIG, the integrated geoscience suite of Total S.A.. Moreover, functions such as minimum, maximum and all standard averages are implemented to set each intersection modifier from the values of the intersected faults' modifiers, hiding the complexity of regions representing intersection between features from the engineer, who only needs to focus on the flow management.



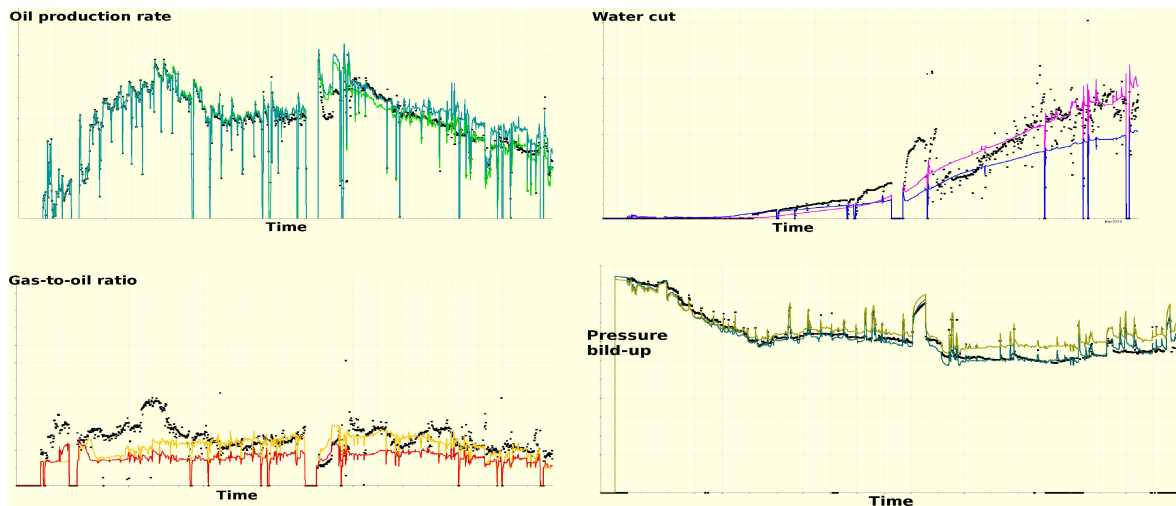
**Figure 1** Left: example of a fault with its throw colouring the surface, and the induced representation in the reservoir grid. Right: Example of regions defined starting from a set of faults, on a production project. Each region is shown with a different color; zones with no defined region are shown in black.

## Results

The method presented in this paper was applied to many production projects, allowing them to introduce property-dependent transmissibilities with the aim to improve their history matching. Due to confidentiality issues as well as space restrictions, in this section only one instance of application of the method will be presented. Further applications to production projects and other new workflows enabled by the current method and tools will be shown in the oral presentation. The method was successfully validated on a history matching process of a known field with reservoir grid dimensions  $165 \times 146 \times 225$ . A previous simulation, performed using standard techniques, was available, and has been used as a baseline. Faults in the baseline simulation were obtained using a common commercial software, but no properties were transferred with them. A new history matching was done once the fault properties were introduced in the grid connections using the proposed method, and the fault properties were included in the multiplier value choice. Three groups of faults have been taken into account in the screening: a northern group, which includes three faults, a central group with four faults and a southern group with two faults. Oil production rate, water cut, gas-to-oil ratio and pressure matching were successfully matched tuning the transmissibility multipliers on the grid faults. Results are shown in Figure 2. As can be seen, oil production data, which was overestimated for late times by the baseline simulation, is better matched with the method presented here. Water cut is also much better matched over all the time domain. It should be noted that the bump in water cut data in Figure 2, which is not matched by either simulation, should be disregarded as it is due to an allocation issue. It can be seen that the gas-to-oil ratio predicted using faults transmissibilities obtained by the current method is also closer to production data, especially for later times, as is pressure build-up. These results provide a benchmark for the proposed algorithm, as well as showing its usefulness in a real-world application with production data.

## Conclusions

A novel tool introduced in the Total's Integrated Geoscience Platform, Sismage-CIG, was presented. The methodology allows managing geological features and their properties in reservoir grid connections, and exporting them directly as simulation files for Eclipse or Intersect. The same tool allows a fine



**Figure 2** Comparison between production data (black points), the baseline simulation, and our method. Top left: oil production rate, baseline (aquamarine) and our method (green). Top right: water cut data, baseline (blue) and our method (magenta). Bottom left: gas-to-oil ratio, baseline (red) and our method (yellow). Bottom right: pressure build-up, baseline (dark green) and our method (dark yellow).

management of multipliers, with special regard towards complex intersections. The tool was validated in synthetic as well as real cases, of which one was presented in this paper. Its promising results can open up new and improved workflows for geological feature handling in reservoir grids.

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