NEW GEOLOGIC GRIDS
FOR ROBUST GEOSTATISTICAL MODELING
OF HYDROCARBON RESERVOIRS

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ABSTRACT

Geostatistical modeling of reservoir facies and petrophysical properties (e.g., porosity and permeability) must be performed in a pre-faulted, deposition space in order to reproduce the true spatial correlations of these properties. A transformation function is therefore required to bring the data from the current position of the reservoir into the modeling space where experimental variograms are computed; reservoir properties are then stochastically simulated in the deposition space and mapped back to the real space.

Current reservoir modeling practice uses a stratigraphic grid to conform to the reservoirs structure (bounding horizons and faults). The (i, j, k)-indexing of the nodes of the cells is used as a discretization of an implicit curvilinear coordinate system which acts as the transfer function to the deposition space. These leads to a very strong underlying assumption: the geological distances (in the deposition space) are a function of the (i, j, k)-indexing.

In the presence of (non-vertical) faults, the cells of the stratigraphic grids are either stretched or squeezed, violating this assumption. Moreover, in the presence of complex structural geology, these grids simply cannot be constructed without tremendous simplifications.

The new proposed approach uses a 3D parameterization of the subsurface yielding an implicit grid that minimizes the distortions of distances imposed by geostatistical simulation algorithms. These new geological grids allow the construction of robust reservoir models whatever the structural complexity of the reservoir.

Additionally, they guarantee the accurate mapping and upscaling of reservoir properties into either structured or unstructured flow simulation grids.

INTRODUCTION

Today, reservoir modelers and engineers use the same 3D reservoir grid definition to construct their respective reservoir models. These grids are "structured" in the sense that each row contains the same number of cells; the same is true for each column which must have the same number of layers. The geoscientist should align the grids with the principal directions of deposition. The engineer should align them to preferential flow directions. However, in
practice, the same grid is often used by both disciplines; only the resolution of the grids will differ. Depending on the oil and gas companies preferred approach, the flow simulation grid is either down-gridded to a finer resolution, or the geological model is up-gridded to a coarser one. Both of these approaches can lead to erroneous results. As we show in this paper, the use of these types of grids has two major shortcomings. Firstly, it is extremely difficult and often impossible to accurately represent any sort of structurally complex reservoirs – models have to be simplified; the geometry of the fault network is modified and some faults are even ignored. Secondly, once the reservoir model is constructed, cells are (i, j, k) indexed with implications that are often ignored. The indexing is commonly used to provide a transformation of the reservoir geometry from its current faulted and folded structure to an un-faulted, unfolded environment assumed to represent the reservoir geometry at the time of sediment deposition. Petrophysical properties such as net-to-gross, porosity and permeability, are stochastically distributed in this deposition space and mapped back onto the reservoir model. As described below, the structured nature of the reservoir grid leads large volume variations from cell to cell which, if not properly taken into account, can lead to erroneous reservoir volume and reserve estimations.

Reservoir modeling therefore suffers from current 3D grid technology both in terms of structural accuracy and petrophysical content. This paper presents a new way to represent accurately both the reservoir structure and the integrity of the property model. Based on the space/time transformation theory (Mallet, 2004), it is possible to disconnect the constraints of structural representation and the distribution of reservoir properties. A ‘Geologic Grid’ is introduced which can be created whatever the complexity of the reservoir structure, while guaranteeing conservation of distances and volumes through the ‘uvt-transform’.

3D RESERVOIR GRIDS – STATE OF THE ART

Structured ‘Pillar’ Grids

Simply put, 3D reservoir grids are constructed by “extruding” columns of cells from the top horizon of a reservoir structure to its base. These columns (or “pillars”) must be aligned to the fault planes which are used as guides for the extrusion process (Figure 1). A column of cells cannot cross a fault plane; and generally cells do not intersect stratigraphic horizons either. As can be seen in Figure 1, the reservoir grid contains the same number of cells at the top of the reservoir than at the bottom and this is also the case within each fault block. Since faults are rarely vertical, this leads to distortions of the cells and large volume variations from cell to cell, especially when comparing layers of cells at the top and at the base of the reservoir.

These constraints lead to two very important assumptions that underlie the work of the majority of reservoir modelers today.
Limitation #1: Representation of Complex Geological Structures

The pillar grid representation works fine when the reservoir geology is relatively simple and faults are near vertical. This configuration can be assumed valid with very thin reservoir intervals or layer cake structures found in many oil sand reservoirs. However, in many hydrocarbon deposits, this is not the case. Faults are rarely vertical and faulting patterns can be quite complex. This is particularly true when the model needs to include multiple reservoirs, some of the overburden or the basement. Figure 2 illustrates complex faulting including Y-, X- and λ-faults. In such a configuration, it is at best extremely tedious to fit a pillar grid to the fault network; in most cases, it is simply impossible. Practitioners must therefore make the costly decision of modifying the fault network by changing the dip and the extension of some of the faults and by removing others from the data set.

Limitation #2: Geostatistical Modeling Approximations

Once constructed, the (i, j, k) indexing of the resulting grid is used to map each cell of the grid into a parametric space assumed to represent the original space of

Figure 1: Pillar representation of a reservoir grid.

Figure 2: Complex faulting configuration.
deposition of the sediments. In this parametric space, all cells are perfectly hexahedral and of the same dimensions. Stochastic simulations of facies and petrophysical properties such as porosity are performed in the parametric space assuming constant cell volumes and correlation distances proportional to index separation distances. Simulated values are then mapped back to the geological domain. Figure 3 (Mallet, 2008), illustrates the mapping from the geological space into the (i, j, k) parametric space. It also points to the artificial distortions of grid cells due to the non-vertical nature of the faults. This leads to large cell volume disparities throughout the reservoir which are generally not considered by the simulation algorithm (for example through a change of support correction or block-kriging, (Deutsch 2002)).

Additionally, the correlation distances (variograms) or geological body (e.g. channels) dimensions imposed on the model are not accurate since they are based on index differences and not curvilinear grid coordinates corrected for the ‘stretching’ or ‘squeezing’ of each cell. This is illustrated in Figure 4: channel objects of constant width are distributed in a pillar-grid; due to the distortions of the cells, channels appear larger in some parts of the reservoir (e.g. top of central block) than in others (e.g. bottom of central block). These artifacts are almost always present in structured reservoir grids; they not only affect net volume calculations but also reservoir connectivity and therefore they can have a non-negligible impact on reserves estimations.

Figure 3: Transformation from the Geological Space to the Parametric Space in a pillar grid (Mallet 2008).

Figure 4: Channel object simulation in pillar-grid; channels width variations are only due to grid distortions (only one out of ten gridlines is displayed for visual clarity).
NEW GEOLOGIC GRIDS

A Space/Time Framework

Mallet (2004) introduced the concept of space/time mathematical framework which consists of parameterizing the subsurface by creating a *uvt-transform*. This transformation maps every \((x, y, z)\) point in the geological space to a \((u, v, t)\) point in the parametric space without having to actually construct explicitly a reservoir grid. Stratigraphic horizons correspond to iso-\(t\) values in the parametric space and are discontinuous across faults as illustrated in Figure 5. The reader is referred to Mallet (2004, 2008) for a complete mathematical description of the *uvt-transform*.

![Figure 5: Example of a *uvt-transform* function corresponding to the curvilinear parameterization of a reservoir (Mallet 2008).](image)

The parametric space can be regularly discretized into elementary volumes of the same dimensions. A reverse *uvt-transform* enables the mapping of these volumes into the geological domain as illustrated in Figure 6. It can be demonstrated (Mallet, 2008) that such transformation conserves volumes and stratigraphic distances. This implies that any stochastic simulation performed in the parametric domain under the assumption of constant cell volume and correlation distances proportional to grid index differences are accurate when the results are mapped back into the geological domain. In other words, current implementations of geostatistical algorithms can be performed directly in the parametric space without the added constraint of correcting for change of support and curvilinear variogram distances.

A word of caution: the *uvt-transform* is different from the simpler *xyt-transform* for which the projection of the parametric space into the geological domain leads to vertical alignment of the columns and incorrect throw across the faults. Additionally, a *xyt-transform* exhibits overlaps of volume element in the parametric space in the presence of reverse faults and other structures.
Geologic Grids Description

A Geologic Grid is the representation of the discretized parametric space in the geological domain as seen in Figure 6. Its hexahedral cells are constrained not to cross layer boundaries; however they are split by the faults, the offsets of the possibly multiple split parts are equal to the displacement that occurred along the faults. This is illustrated in Figure 7 where a sediment volume is deposited, faulting occurs splitting the volume followed by a displacement along the fault plane.

Columns of cells from the parametric space are orthogonal to their respective stratigraphic unit boundaries when projected into the geological space (see Figure 6); layers of cells show the correct throw offset across fault cuts even in the case of reverse faulting.

**Advantage #1: Representation of Complex Geological Structure**

The first advantage of the \textit{uvt-transform} is that it disconnects the structural model from the property model. A Geologic Grid can therefore be created whatever the complexity of the fault network and populated with reservoir properties. Figure 8 shows an example in a fault rift system with complex faulting, typically impossible to model with a single structured grid.
Advantage #2: Accurate Geostatistical modeling

The Geologic Grid conserves stratigraphic distances and volumes. The channel objects realization of Figure 4 is represented through the \textit{uvt-transform} in the Geologic Grid of Figure 5. The simulation displays correctly all channels at the same width, exhibiting therefore the net volume and connectivity imposed by the model parameters.

Figure 9: Channel object simulation in a Geological Grid. All channels correctly have the same width (only one out of ten gridlines is displayed for visual clarity).

ADDITIONAL REMARKS

Non Depositional Properties

Stochastic simulation in the parametric domain concerns depositional properties such as rock types and porosity. Post-depositional properties such as water saturation must be computed in the geological (x, y, z) space. An elementary volume of the Geologic Grid therefore needs to contain possibly a different value for each split part. Figure 10 shows a section of a Geologic Grid on which is displayed (a) a depositional property and (b) a non-depositional property.
Flow Simulation Grids

The Geologic Grid should become the tool of the geoscientists, ideal for geostatistical modeling of reservoir properties and in-place volume calculations. Reservoir engineers, however, still require a structured grid as input to commercial flow simulators. It is possible to construct structured grids that stair-step at fault with vertical or sub-vertical columns, allowing the representation of complex geological structures while maintaining the orthogonality constraints necessary for optimal numerical flow simulation. In the presence of reverse faulting, the indexing of the grid often contains gap or null cells that prevent it from supporting accurate geostatistical modeling using conventional (i, j, k) index transform.

Upscaling

A tight connection between the Geologic Grid and the Flow Simulation Grid is facilitated by the \textit{uvt-transform} as it provides an exact positioning of each fine Geologic Grid into the coarser cells of the flow simulation grid, respecting stratigraphic and faulting constraints.

CONCLUSIONS

Today, reservoir modeling is impaired by the use of pillar-based reservoir grids which are limited to simpler reservoir geometry and violates the underlying assumptions of most implementations of geostatistical algorithms. This paper introduces the Geologic Grid as a new support ideal for geostatistical modeling of reservoir properties. It is a discretization of the deposition space with a representation in the geological space through the \textit{uvt-transform}. It also enables specific modeling of both depositional and post-depositional properties. As the \textit{uvt-transform} allows the separation of the structural model and the property model, a geostatistical property model can therefore be constructed whatever the structural complexity of the oil and gas reservoir.
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REFERENCES