A prototype workflow for Fault Facies geo-modeling

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1. Introduction

Faults commonly act as barriers or baffles in petroleum reservoirs, but may sometimes act as conduits for fluid flow. Understanding the properties of faults and fault zones, and properly capture them in reservoir models, is crucial for reliable forecasting of production performance and reservoir response.

Outcrops show that faults on reservoir scale are volumetric elements, which can be described in terms of displacement and petrophysical alteration of a volume of host rock surrounding this displacement. Yet, conventional geological modeling tools, like Havana™ (Hollund et al 2002), TransGen™ and others, represent fault zones as surfaces. The impact of faults on fluid flow is included through transmissibility multipliers across fault surfaces, augmented with non-neighbor connections to represent ducts along fault surfaces, often derived in an *ad hoc,* deterministic manner.

The present work is part of the ongoing Fault Facies Project, (Tveranger et al. 2004, 2005a, 2005b), which aims at generating a method and a fault feature database structure that allows fault zones to be modeled as 3D volumes. This yields a physically more correct representation of faults as seen in nature. Using a volumetric description of the fault zone allows frequency, distribution and petrophysical properties of fault zone elements to be modeled stochastically. The method does, however, require the use of boundary values derived from statistical analysis of geometries, dimensions, distributions and petrophysical properties from a large number of field observations of faults and fault zones in different lithologies. A database designed for this method is currently being compiled by the Fault Facies project. The method will lead to a more correct model for flow simulation when non-discrete fault zones are present, as the uncertainty of the fault zone can be described formally, and included in flow simulation studies.
In the following, a prototype Fault Facies model is presented which shows that the method is technically viable.

2. Grid modeling concept

The fault is initially defined in a coarse grid, in the traditional way, as a surface. The fault zone is defined as a certain volume around the fault, in which host rock properties are altered or affected by recurrent fault movements. Due to the commonly large heterogeneities present in the fault zone, it is extracted from the full model and handled separately using a finer grid resolution. The fault zone LGR is subsequently merged with the full model, as illustrated in Figure 1.

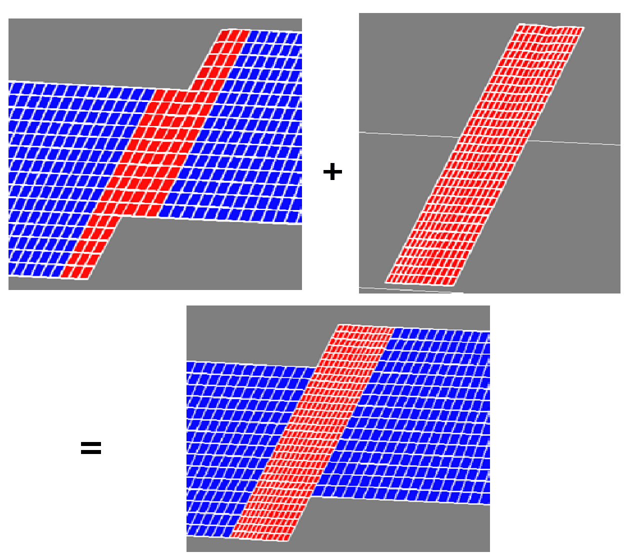

Figure 1: Merging of coarse and fine grid.

In this figure, the fault zone volume has a width of three grid cells to the left and three grid cells to the right of the fault plane. The fine grid in the fault zone is constructed as follows. Start with the coarse grid cells belonging to the fault zone. Each grid cell is refined, for example a factor two in x-, y-, and z-direction. These cells are stretched in z-direction to ensure that the grid has the same height on both sides of the fault plane. This is shown in Figure 2 where a single slip plane occurs to the leftmost edge of the fault zone. Generation of the fault zone LGR and the merging of the fine and coarse grids are implemented in Havana™.

The additional grid volume, generated by stretching the grid in z-direction, comprises fault affected rocks originating from layers above and below the zone of interest. In the fault zone these rocks may typically mix with the original facies producing complex architectures.

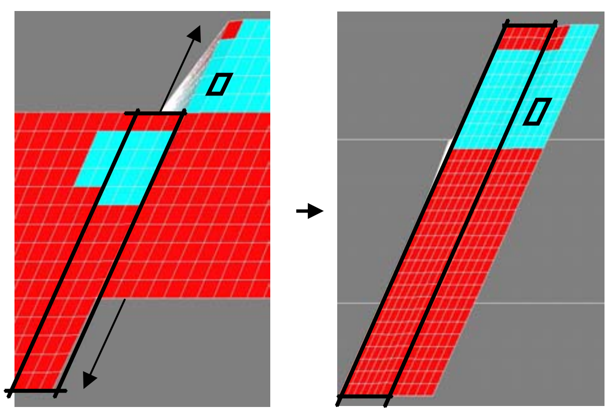

Figure 2: Stretching of cells in the fault zone grid.

3. Property modeling

Facies and petrophysical parameters are modeled separately for the fault zone LGR and coarse grid before the merging. Sedimentary facies and their petrophysical properties are simulated on the coarse grid producing a prior facies model, which describes how facies are distributed before the faulting occurs.

3.1 Facies modeling

The prior model is a conventional sedimentary facies and petrophysical model simulated by using a stochastic method.

For the present purpose, four "fault facies associations" are identified in the fault zone:
1) Unmodified host rock/ lenses (equal to the facies present prior to faulting).
2) Transformed host rock, i.e. fault rocks generated from the faulting process (e.g. gouge or breccias).
3) Facies originating from the zone above the reservoir.
4) Facies originating from the zone below the reservoir.

The transformation from unmodified sedimentary facies to fault products (fault facies) will in this case be handled using empirical relationships between strain and property change of the host rocks conditioned by a simplified strain distribution field as input. In the fault zone the geometric distribution of fault products versus facies from above or below will be handled as a 3D probability distribution by using a "Fault Product Distribution Factor" (FPDF).

The FPDF, which describes the probability of a specific element from a specific stratigraphic level occurring in a given position in the fault zone, is estimated by using the fact that fault zone architecture is largely determined by the number and distribution of discrete slip planes in the fault zone. This factor is intimately linked to the mechanical properties of the host rock, fault geometry, fault history and strain distribution. Consequently, estimating a precise, high-resolution FPDF is not possible without access to a very extensive empirical database (Tveranger 2005b) on fault zone architecture, and an understanding of the physical processes of faulting.

However, for the purpose of using FPDF in a prototype model, the issue can be addressed in a simplified manner using easily accessible parameters such as fault zone width, angle and throw. The FPDF is here considered in terms of a simple geometric problem, which helps us to identify end-members as shown in Figure 3 (discrete number of slip planes – all simplified as parallel and of equal length) and Figure 4 (continuum of slip planes with different centers of gravity). In these figures, white areas indicate the distribution of fault facies belonging to a specific stratigraphic unit in the fault zone, and black areas indicate where facies from stratigraphic units above and below are distributed. The resulting 3D probability distribution of Fault Products is resampled into the fault zone grid to produce an intensity map for use in the actual Fault Facies modeling. Facies intensity maps for fault zone rocks originating above or below the modeled stratigraphic unit are also derived from the FPDF.

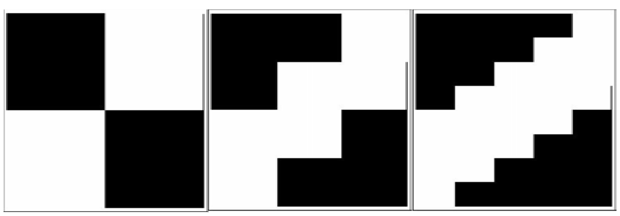

Figure 3: Fault Product Distribution Factor with one, two and four slip planes symmetrically located in the fault zone. Slip planes are here simplified as having uniform displacement and spacing. The fault zone is mapped to a unit square.

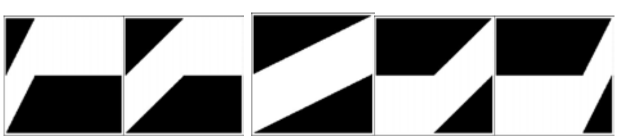

Figure 4: Fault Product Distribution Factor for a continuum of slip planes. The figure shows the effect of moving the center of gravity for the frequency distribution of the slip planes from left to right through the fault zone.

3.2 Petrophysical modeling

Petrophysical parameters are simulated as for sedimentary facies using Gaussian random fields, with empirically derived parameter values for the different fault facies included.

4. Workflow

The workflow for the whole concept is implemented in RMS and can be summarized as follows:

1. Simulate facies and petrophysics on the coarse grid according to the prior model.
2. Define the fault zone.
3. Define new grid for the fault zone.
4. Define facies intensity parameters for the fault zone from the FPDF.
5. Estimate strain in the fault zone.
6. Simulate facies in fault zone conditioned to intensity parameters.
7. Use strain (possibly with noise) to get transformed facies.
8. Simulate petrophysical variables in fault zone.
9. Merge fault zone grid with the rest of the reservoir grid.

The resulting grid and properties can now be taken into a fluid flow simulator.

5. References

Hollund, K., Mostad, P., Nielsen, B.F., Holden, L., Gjerde, J., Contursi, M.G., McCann, A.J., Townsend, C. & Sverdrup, E. 2002: Havana – a fault-modelling tool. Norwegian Petroleum Society Special Publication 11, 157-171.

Tveranger, J., Braathen, A. & Skar, T. 2004: Incorporation of fault zones as volumes in reservoir models. Bolletino di Geofisica teorica ed applicata 45, 316-318.

Tveranger, J., Aanonsen, S.I., Braathen, A., Espedal, M., Fossen, H., Hesthammer, J., Howell, J., Pettersen, Ø., Skorstad, A., Skar, T., Sverdrup, E. & Syversveen, A.R. 2005a: The Fault Facies Project – 3D modelling of faults and tectonic impact in petroleum reservoirs. Abstracts and Proceedings of the Geological Society of Norway 1. 121-122.

Tveranger, J., Braathen, A., Skar, T. & Skauge, A. 2005b: Centre for integrated petroleum research – research activities with emphasis on fluid flow in fault zones. Norwegian Journal of Geology, 85, 63 -72.