3D Fault Zone Representation in Reservoir Modelling

Vasileios Papanikolaou and Tom Manzocchi

Fault Analysis Group, UCD School of Earth Sciences, University College Dublin, Belfield, Dublin 4, Ireland

vasileios.papanikolaou@ucdconnect.ie

1) Introduction: Fault Segmentation and Fault Zone Complexities

It is widely known that faults strongly affect entrapment of hydrocarbons and reservoir compartmentalization. It is vital therefore to be able to predict fault zone complexity in order to have accurate flow models and valid simulation results. Most fault-related models that are based on seismic interpretation consider faults as single surfaces (**Fig. 1**). However, faults rarely comprise one single slip surface; instead, they form segmented arrays (both vertically and laterally). This segmentation results in complicated zones, with features including relay zones, fault-bounded lenses and regions of normal or reverse drag within the wall rocks (**Fig. 2**).

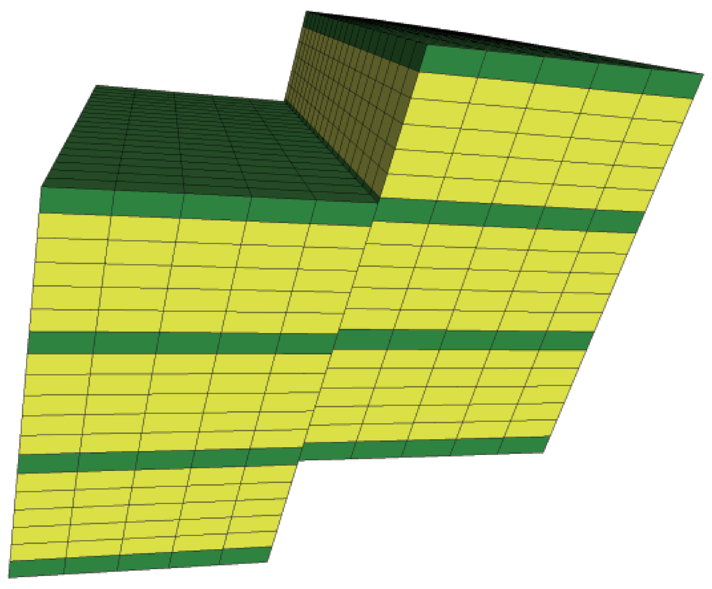

Fig. 1: Conventional fault model presenting a sub-vertical faults as a simple surface (Fredman et al., 2007)

Fig. 2: Example of a complex fault zone, taken from an outcrop in a lignite mine in Ptolemais, N. Greece

a)

b)

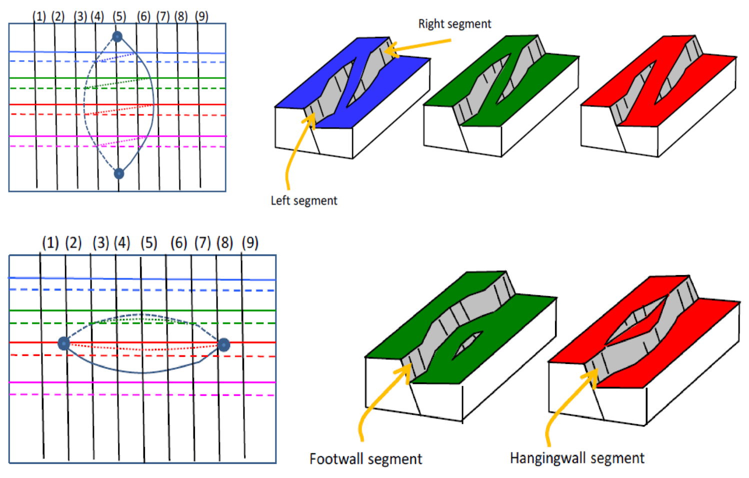

Fig. 3: Block diagrams illustrating the different geometries in 3D between a neutral relay (a) and a dip relay (b) zone. (Fault Analysis Group, 2011 – Unpublished data)

Vertical and lateral segmentation results in the formation of two end-member relay geometries; neutral and dip relay zones (**Fig. 3**). Both types of relays represent holes in otherwise continuous fault surfaces; however, they have very different implication on across-fault connectivity. Unbreached, neutral relays provide vertical pressure communication between the same layers while dip relays form fault-bounded lenses and therefore, no across-fault connectivity is provided, even when the relay is unbreached.

Fig. 4 and **Fig. 5** show the implication of an unbreached neutral relay ramps on fluid flow. Manzocchi et al. (2010) examined how unbreached relay ramps represent efficient conduits for vertical communication in terms of pressure drawdown and tracer saturation (**Fig. 4**). Different kv/kh ratio cases were chosen for different fault geometries (single fault vs. unbreached relay ramp). At the same time, Rotevatn et al. (2009) studied the effect of the Delicate Arch Ramp (National Park, Utah) on fluid flow (**Fig. 5**) between single faults and unbreached relays (for different permeability values).

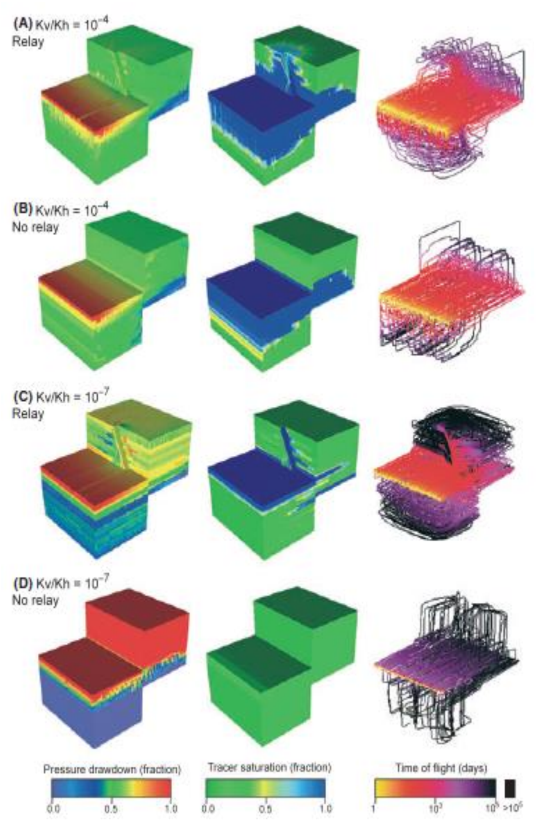

Fig. 4: Flow models between relay ramps and single fault surfaces for a number of kv/kh ratios. From Manzocchi et al. (2010)

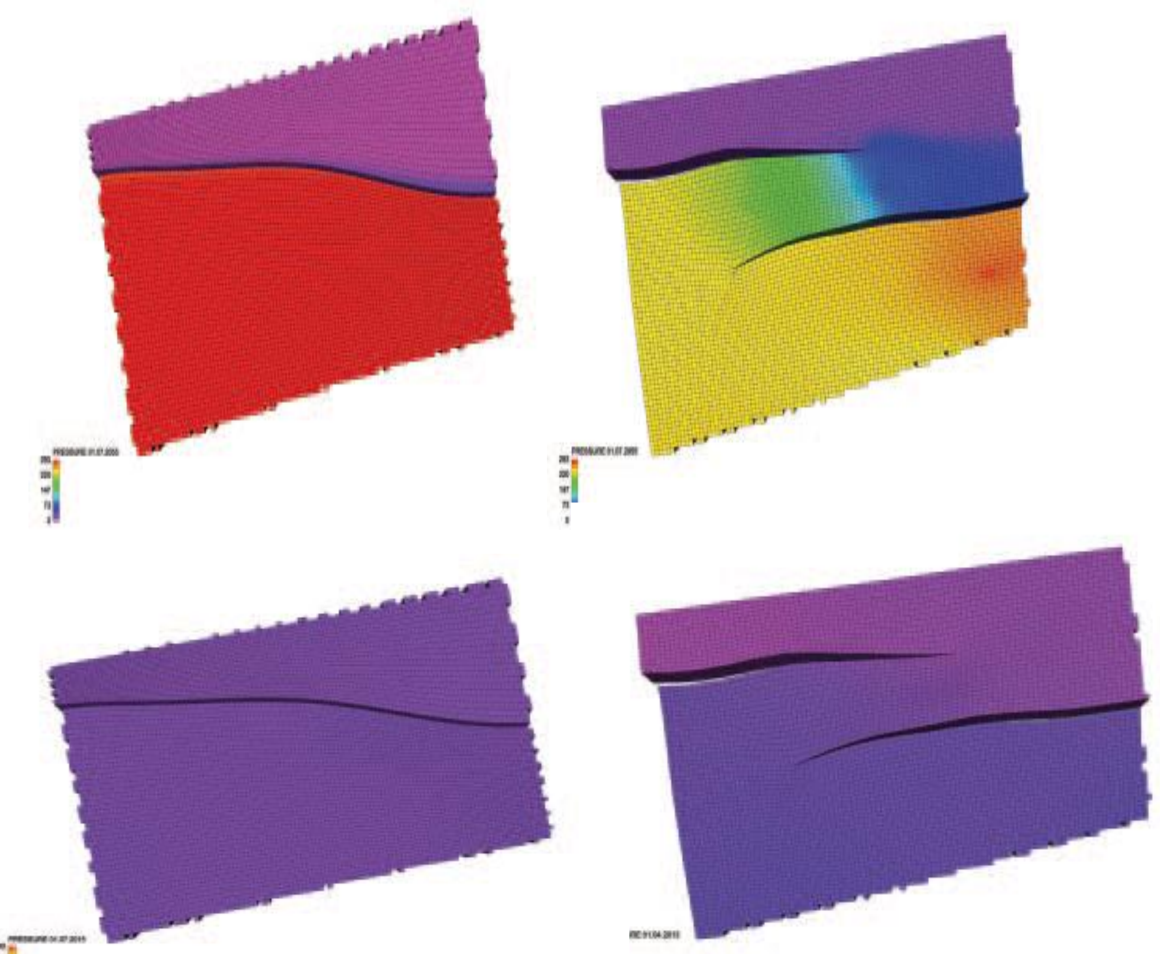

Fig. 5: Dynamic models illustrating pressure drawdown between a single fault and an unbreached relay ramp . From Rotevatn et al. (2009)

2) Incorporation of Faults in Flow Models: Defining the Problem

Most of the industry-standard flow simulation tools use the Corner-Point Grid (GRDECL) format (**Fig. 6**). Despite the grid's simplicity in solving Darcy's equations, COORD lines need to be straight (otherwise grid will be distorted by cross-cutting pillars) and this limitation has a strong impact on modelling complicated structures such as reverse, Y, X or λ faults. An industry-accepted solution to overcome this limitation is to model faults as stair-steps (**Fig. 7**); however, the incorrect representation of the juxtaposition and the loss of throw are some of the drawbacks of this method. In summary, most fault-related models represent faults as 2D surfaces rather than 3D volumes, ignoring that way the internal fault zone complexity (displacement partitioning).

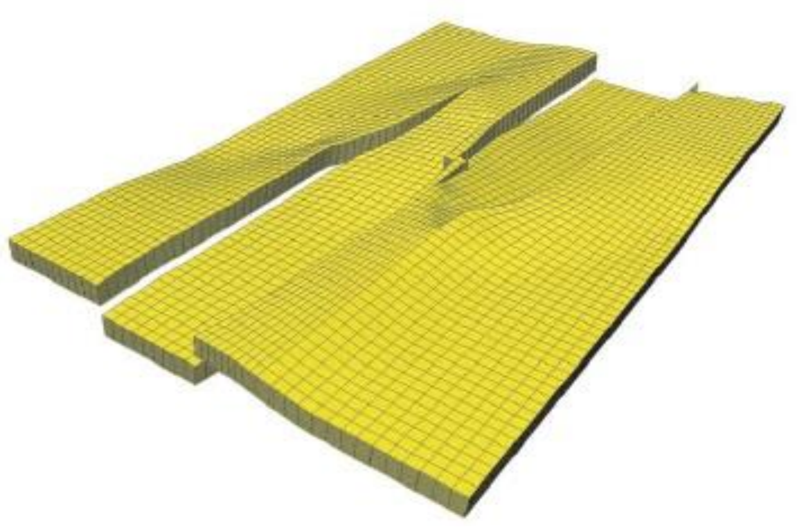

Fig. 6: The Corner-Point Grid format is widely used by flow simulation tools. It consists of hexahedral cells; the COORD lines need to be straight. (Rotevatn et al. (2009))

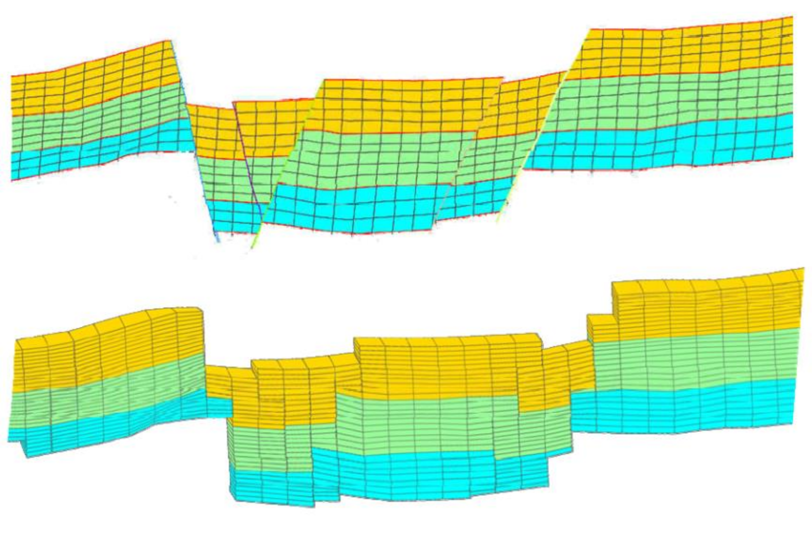

Fig. 7: Stair-stepping faults are the industry-accepted solution for modelling complicated structures. Taken from Gringarten et al. (2009)

3) Approaching the Problem: Aim of Project and Previous Studies

The initial aim of this research is to create a number of 3D geocellular fault zone models that honour realistic structural complexity and to illustrate the effect of this complexity on fluid flow. Ultimately, this study aims to improve available methods for incorporating realistic 3D fault complexity in reservoir modelling.

Previous research on fault modelling includes Local Grid Refinement (LGR) methods for modelling fault zones explicitly. Fredman et al. (2008) created refined grids with the purpose of modelling faults as deformed rock volumes, rather than 2D planar surfaces **(Fig. 8)**.

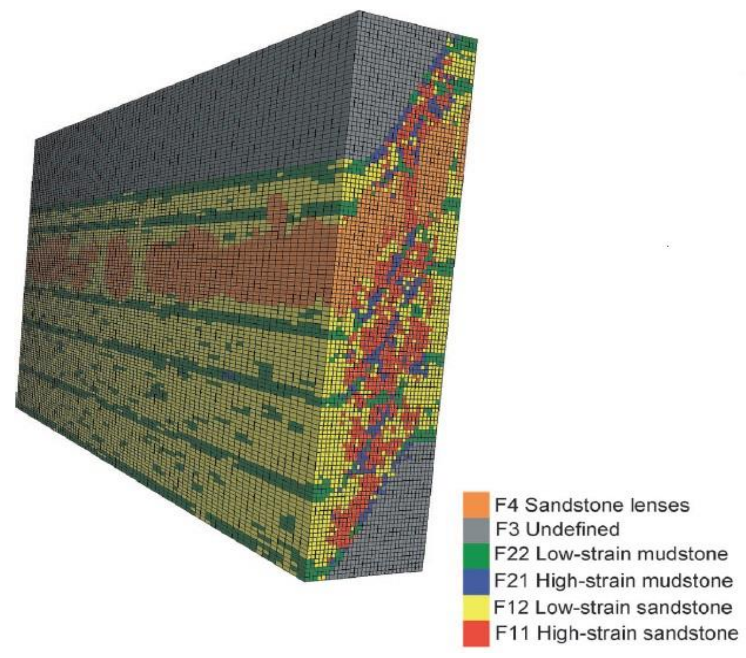

Fig. 8: Fault Facies modelling approach for 3D high resolution fault zone models. This figure illustrates sand lenses and other parts of deformed rock within the fault zone. From Fredman et al. (2008)

In a different approach, Manzocchi et al. (2008) developed an upscaling method for representing complex 3D fault zone structures in simulation models, by estimating transmissibilities between the centres of two connected cells (**Fig. 9**).

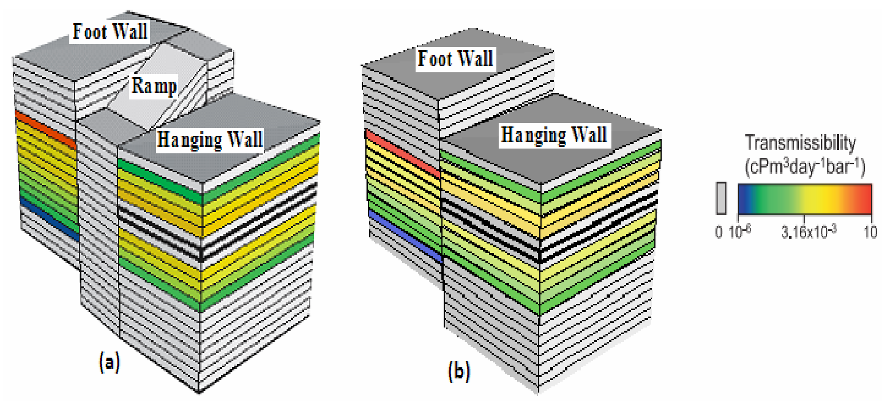

Fig. 9: (a) High resolution model of an unbreached relay ramp (b) Upscaled model containing the same 3D fault zone structure. From Manzocchi et al. (2008)

This method was furtherly developed by Islam (2015) with an improved Flow-Based Geometrical Upscaling, to deal with structures that they are longer than 1 cell (**Fig. 10**).

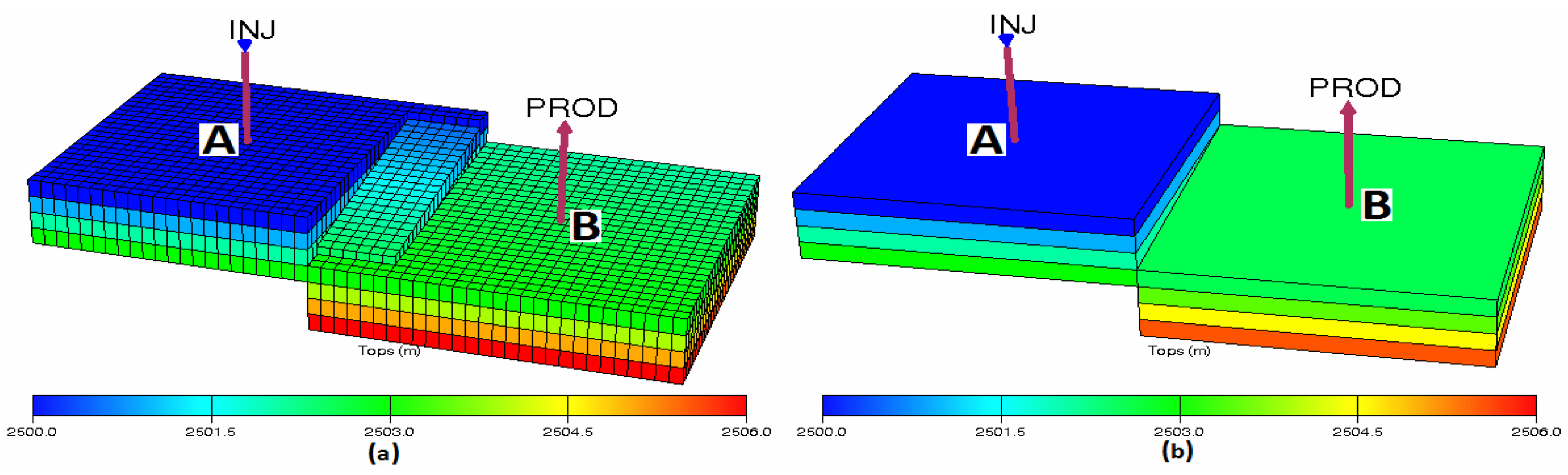

Fig. 10: (a) High resolution model of an unbreached relay ramp. (b) Upscaled model containing the same 3D fault zone structure as a function of neighbour and non-neighbour connections. From Islam (2015)

4) Approaching the Problem: Work to Date and Future Plans

The different response in fluid flow between a neutral and a dip relay zone will be the first question to be answered. The distinction between those types of unbreached relay on flow is not widely understood, partly because of the difficulty in modelling dip relays. Neutral relays can be modelled with conventional Corner-Point Grids (**Fig. 4, Fig. 7, Fig. 8**), but dip relays cannot. However, the recently-developed Generic Simulation Grid (GSG) provides the ability to model faults with curved or truncated pillars.

A neutral relay has been modelled in the conventional GRDECL format, along with a vertical displacement gradient (**Fig. 11a**). On **Fig. 11b**, a model of an unbreached dip relay with curved pillars is illustrated. Note that there is no across-fault connectivity between the segments.

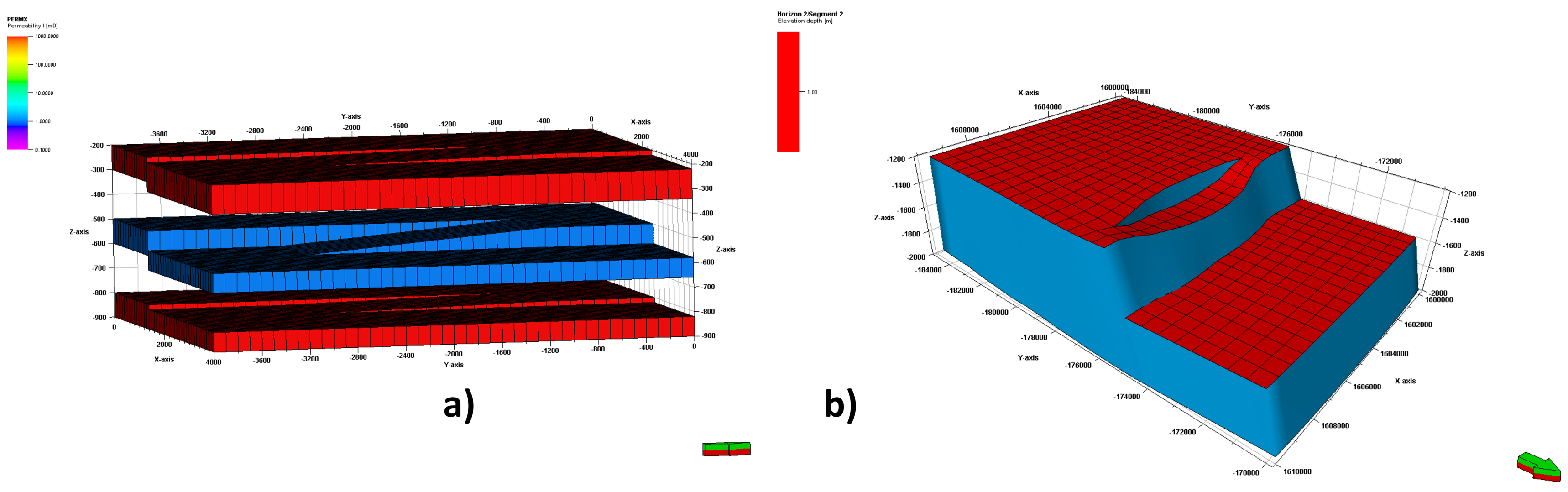

Fig. 11: Neutral relay zone model with vertical displacement gradient. The dip of the ramp increases with increasing displacement (**Fig. 11a**). On **Fig. 11b**, a the geometry of a dip relay is illustrated.

Future work plans include the creation of a series of models and the examination of different responses to flow between:

- A neutral and a dip (contractional/extensional) relay zone
- Single slip surfaces and complicated (realistic) fault-zone structures
- Complicated fault-zone geometries by the use of straight pillars in the GRDECL format (stair-step faulting) and curved pillars in the GSG format.
- Fault-zone geometries including both structured and unstructured meshes

5) References

Fredman, N., 2007, Quantification of fault zone features in siliciclastic rocks: Implications for 3D fault modelling and fluid flow, University of Bergen, Bergen.

Fredman, N., Tveranger, J., Cardozo, N., Braathen, A., Soleng, H., Roe, P., Skorstad, A., and Syversveen, A. R., 2008, Fault facies modeling: Technique and approach for 3D conditioning and modeling of faulted grids: AAPG Bulletin, v. 92, p. 1457-1478.

Gringarten, E., A. Haouesse, B. Arpat, and L. Nghiem, 2009, Advantages of Using Vertical Stair Step Faults in Reservoir Grids for Flow Simulation, SPE Reservoir Simulation Symposium 2009, The Woodlands, TX; United States, p. 1242-1249.

Islam, M. S., 2015, Upscaling methods for unclusion of fault zone structure into flow simulation models, University College Dublin (Unpublished Doctoral Thesis)

Manzocchi, T., C. Childs, and J. J. Walsh, 2010, Faults and fault properties in hydrocarbon flow models: Geofluids, v. 10, p. 94 - 113.

Manzocchi, T., A. E. Heath, B. Palananthakumar, C. Childs, and J. J. Walsh, 2008, Faults in conventional simulation models: a consideration of representational assumptions and geological uncertainties: Petroleum Geoscience, v. 14, p. 91-110.

Rotevatn, A., S. J. Buckley, J. A. Howell, and H. Fossen, 2009, Overlapping faults and their effect on fluid flow in different reservoir types: A LIDAR-based outcrop modeling and flow simulation study: AAPG Bulletin, v. 93, p. 407-427.

Rotevatn, A., J. Tveranger, J. A. Howell, and H. Fossen, 2009, Dynamic investigation of the effect of a relay ramp on simulated fluid flow: geocellular modelling of the Delicate Arch Ramp, Utah: Petroleum Geoscience, v. 15, p. 45-58.

Acknowledgements

This research is part of the industry-funded QUAFF2 project