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A method for generating volumetric fault zone grids for pillar gridded reservoir models

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ABSTRACT

The internal structure and petrophysical property distribution of fault zones are commonly exceedingly complex compared to the surrounding host rock from which they are derived. This in turn produces highly complex fluid flow patterns which affect petroleum migration and trapping as well as reservoir behavior during production and injection. Detailed rendering and forecasting of fluid flow inside fault zones require high-resolution, explicit models of fault zone structure and properties. A fundamental requirement for achieving this is the ability to create volumetric grids in which modeling of fault zone structures and properties can be performed. Answering this need, a method for generating volumetric fault zone grids which can be seamlessly integrated into existing standard reservoir modeling tools is presented. The algorithm has been tested on a wide range of fault configurations of varying complexity, providing flexible modeling grids which in turn can be populated with fault zone structures and properties.

1. Introduction

Faults are encased in three-dimensional bodies of deformed rock known as fault zones. Shape and size of the fault zone may vary according to tectonic style, displacement magnitude and mechanical properties of the host rock, but generally it can be subdivided into a fault core, accommodating the bulk of deformation, and a surrounding damage zone, both displaying structural elements such as lenses, slip surfaces, fractures and deformation bands (Braathen et al., 2009; Caine et al., 1996; Chester and Logan, 1986; Peacock et al., 2000). The inherent structural and petrophysical complexity of fault zones produces correspondingly complex flow patterns inside and across the fault zone (Antonellini and Aydin, 1994, 1995; Caine et al., 1996; Fisher and Knipe, 2001; Fowles and Burley, 1994; Odling et al., 2004); thus faults can act both as pathways and obstacles to sub-surface fluid flow (Caine et al., 1996; Chester and Logan, 1986; Manzocchi et al., 2008, 1999; Seront et al., 1998) and considerably influence petroleum migration, accumulation and recovery.

Characterizing fault properties and understanding fault impact on flow paths and reservoir dynamics through modeling remain key issues for optimizing production and exploration strategies (Fisher and Jolley, 2007). However, these efforts are hampered by the inherent difficulty of describing structural complexity and petrophysical heterogeneity of entire fault zones based on spatially constrained outcrops representing a limited range of scales compared to those observed in the subsurface, and a lack of unified classification systems adapted to the needs of 3D modeling and simulation (Braathen et al., 2009). Limitations related to modeling conventions, grid types, grid resolution and computational cost further constrain the level of detail that can be included in field-sized simulation models. The pragmatic solution to these issues has been to simplify the way in which faults and fault properties are implemented in geo- and simulation-models (Manzocchi et al., 2010, 2008).

Traditional 3D reservoir models incorporate faults as planes with grid-split offsets capturing interpreted fault position and displacement. Faults are commonly treated as pillars or stair steps in 3D grids (by RMS^{TM}, PETREL^{TM}). Some modeling tools (SKUA-GOCAD^{TM}, JewelSuite^{TM}) split grid blocks exactly at the position of faults to honor the structural model (Thom and Hocker, 2009). Initial attempts to implement effects caused by petrophysical heterogeneities known to occur in faults involved heuristic iterative adjustment of fault plane transmissibility in the simulation model during history matching of dynamic well data. This often produces geologically unrealistic results, and runs the danger of compensating for effects within the simulation model which are

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Abbreviations: FZG, fault zone grid; LGR, local grid refinement

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not related to faults (Fisher and Jolley, 2007).

The need to provide more accurate fault property models based on geological observation and reasoning rather than history matching alone, has produced several modeling methods. Typically these focus on individual aspects or characteristics observed in faults (e.g. juxtaposition relations, clay smear etc.) while adapting to the constraint that faults are represented as planes in the model. Well known methods include Allan diagrams (Allan, 1989; Knipe, 1997), clay smear potential (CSP) (Bouvier et al., 1989), shale smear factor (SSF) (Lindsay et al., 1993) and shale gouge ratio (SGR) (Yielding et al., 1997). Combined with fault rock thickness estimation methods (Childs et al., 1997; Walsh et al., 1998) and appropriate permeability algorithms (Manzocchi et al., 2010, 2008, 1999), these methods can be used to calculate permeability across the fault plane at any given point, and are presently employed in most industrial reservoir modeling software suites.

Although offering a pragmatic solution to a complex problem, the fundamental shortcomings and limitations of this approach have been pointed out by several workers (Fredman et al., 2008; Manzocchi et al., 2010, 2008; Tueckmantel et al., 2012; Tveranger et al., 2005). These methods are restricted by the convention of representing complex fault zones, which are essentially 3D geological features, as membranes.

As pointed out by previous studies (Manzocchi et al., 2008; Rivenæs and Dart, 2002; Tveranger et al., 2005), representing fault zones as volumetric entities with explicit fault rock grid blocks could potentially facilitate improved handling, and thus also forecasting of fluid flow in fault zones. However, efforts towards producing explicit fault zone models have been fraught by four key problems: 1) A lack of systematically quantified descriptions of the spatial distribution of fault rock facies (Braathen et al., 2009), 2) a lack of key petrophysical data such as two-phase flow properties of fault rocks (Al-Busafi et al., 2005; Al-Hinai et al., 2008; Tueckmantel et al., 2012), 3) a high computation cost related to the necessity of using high-resolution grids, and 4) a lack of robust upscaling techniques for highly heterogeneous rocks.

Providing a platform where 3D fault zone architectures can be implemented in reservoir models will in our mind encourage further research on all four issues. The aim of the present work is to describe a method for generating 3D fault zone grids enclosing fault traces in corner-point grids with pillar fault representation which can subsequently be populated with fault zone structural elements and their petrophysical properties. This has also been addressed in previous works (Fachri et al., 2011; Fredman et al., 2008, 2007; Soleng et al., 2007; Syversveen et al., 2006). As not all reservoir modeling tools support facies and petrophysical modeling on locally refined grids (e.g. PETREL^{TM} and RMS^{TM} cannot), our fault zone grid generation method generates two grid files (both in corner-point format): a discrete fault zone grid and a merged grid of the entire reservoir model where the fault zone grid is incorporated as LGRs. Thus, this method could work in conjunction with various reservoir modeling tools regardless of whether the tools support property modeling on LGRs or not. The method presented has been tested to work seamlessly with the reservoir modeling tool RMS^{TM} and industry standard fluid flow simulator

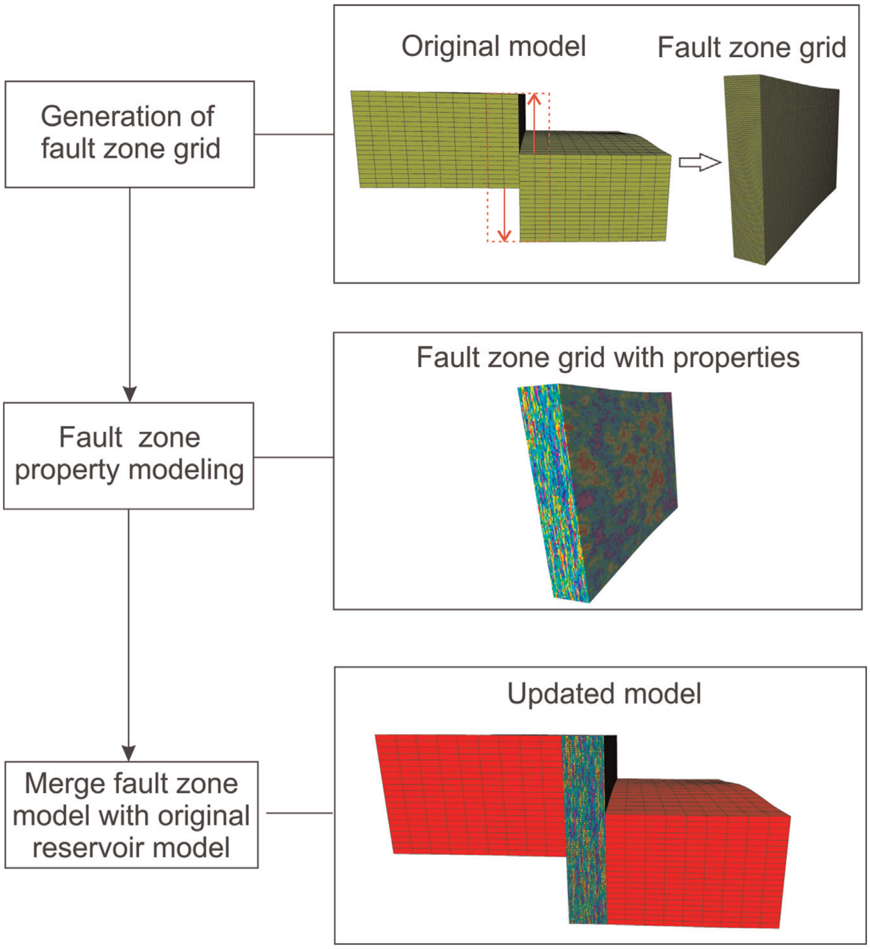

Fig. 1. Schematic workflow for generating fault zone grids and its application in reservoir modeling. The red rectangle from the original model indicates the defined fault zone width. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)