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# Fluid Flow in a Fractured Reservoir Using a Geomechanically-Constrained Fault Zone Damage Model for Reservoir Simulation

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## Abstract

Secondary fractures and faults associated with larger, reservoir scale faults affect both permeability and permeability anisotropy and hence may play an important role in controlling the production behavior of a faulted reservoir. It is well known from geologic studies that there is a concentration of secondary fractures and faults in a damage zone adjacent to larger faults. Because there is usually inadequate data to incorporate damage zone fractures and faults into reservoir simulation models, in this study we utilize the principles of dynamic rupture propagation from earthquake seismology to predict the nature of fractured/damage zones associated with reservoir scale faults. We include geomechanical constraints in our reservoir model and propose a workflow to more routinely incorporate damage zones into reservoir simulation models. The model we propose calculates the extent of the damage zone along the fault plane by estimating the stress perturbation associated with dynamic rupture propagation. Fractures created by the stress pulse accompanying rupture propagation enhance permeability along reservoir scale faults in both the horizontal and vertical directions. We calibrate our modeling with observations from a number of studies and show that dynamic rupture propagation gives a reasonable first order approximation of damage zones in terms of permeability and permeability anisotropy in order to be incorporated into reservoir simulators.

## Introduction

Fractures present both problems and opportunities for exploration and production from hydrocarbon reservoirs. The heterogeneity and complexity of fluid flow paths in fractured rocks always makes it difficult to predict how to optimally produce a fractured reservoir. It is usually not possible to define the geometry of the fractures and faults controlling flow and it is difficult to integrate data from markedly different scales associated with faults mapped in seismic surveys and those seen in wellbore image logs. A number of studies in hydrogeology and the petroleum industry have dealt with modeling fractured reservoirs.[1-4] Various methodologies, both deterministic and stochastic, have been developed to model reservoir heterogeneity on hydrocarbon flow and recovery. The work by Smart et al.[5], Oda[6-7], Maerten et al.[8], Bourne and Willemse[9], and Brown and Bruhn[10] quantify the stress sensitivity of fractured reservoirs. Several studies[11-13] that include fracture characterizations from wellbore images and fluid conductivity from the temperature and the production logs indicate fluid flow from critically stressed fractures. Additional studies emphasize the importance and challenges of coupling geomechanics in reservoir fluid flow.[14-16] These studies found that geomechanical effects may be very significant in some of the fractured reservoirs.

Secondary fractures and faults associated with larger scale faults appear to be quite important in controlling the permeability of some reservoirs. Densely concentrated secondary fractures and faults near larger faults are often referred to as damage zones, which are created at various stages of fault evolution: prior to faulting[17-19], during fault growth[20-25], and during the earthquake slip events[25-28] along the existing faults associated with rupture propagation.

Lockner et al.[29] and Vermilye and Scholz[23] show that the damage zones from the pre-faulting stage are very narrow and can be ignored for reservoir scale faults. The damage zone formed during fault growth can be modeled using dynamic rupture propagation along a fault plane[30-33].

In this paper, we first introduce a reservoir in which there appears to be significant permeability anisotropy associated with flow parallel to large reservoir scale faults. Next, we build a geomechanical model of the field and then discuss the relationship between fluid flow and geomechanics at well scale fracture and fault systems. To consider what happens in the reservoir at larger scale, we will utilize dynamic rupture modeling to theoretically predict the size and extent of damage zones associated with the reservoir scale faults. Finally, we utilize fine scale fluid flow simulations to illustrate the effects of these damage zones on permeability and permeability anisotropy of the reservoir. In contrast to static dislocation models due to slip events, which demonstrates the damage effects only at the tip of the existing faults, dynamic rupture propagation technique defines the damage zone all along the fault.