

# Reservoir Geomechanics

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Reservoir-geomechanical Simulation of Caprock Integrity During Pressure Maintenance Mark D.  
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praise for reservoir geomechanics

a comprehensive overview of the key geologic geomechanical and engineering principles that govern the development of unconventional oil and gas reservoirs covering hydrocarbon bearing formations horizontal drilling reservoir seismology and environmental impacts this is an invaluable resource for geologists geophysicists and reservoir engineers

geomechanics is the basic science for many engineering fields including oil and gas recovery mining civil engineering water supply etc as well as for many environmental sciences including earthquake prediction ecology landscape dynamics and explosion works historically the major concepts of geomechanics were founded on the methods of the elasticity theory and the static equilibrium of joints with solid friction underground hydrodynamics was developed quite separately and included only simple conventional ideas of elastic pore space deformation today the situation is drastically different tremendous achievements in numerical computer technique have eliminated many of the routine difficulties of problem solution with respect to selected mathematical models as the result major efforts now are applied to sophisticated experimental studies and to new applications of generalized continuum theories of course traditional rheological schemes have been adjusted to be into account the real properties of such geomaterials as soils rocks and ice the main changes have been connected with the kinematics of the internal structure

of geomaterials that influences their strength and that can play unusual roles in dynamic processes the theoretical considerations are in good agreement with experimental observations in situ because of precise measuring devices impact of modern physics concepts and large scale monitoring

conventional geomechanics cannot provide suitable modes of behavior and performance for today's unconventional reservoirs such as the evolution of porosity permeability relationships with multiphysics coupled effects which ultimately help determine production rates unconventional reservoir geomechanics delivers a reference that discusses a variety of approaches tailored in developing geomechanical models and provides a smarter tool to predict hydrocarbon extraction specifically for unconventional reservoirs starting with a full explanation on a more unified theoretical framework discussing permeability characterization the authors advance to offer a full range of new modelling solutions followed by a series of lab scale and field scale applications to match the history verified models bridging a gap for engineers to fully understand the interactions of multiple processes in field scales from theory to practice going a step further other applications such as CO<sub>2</sub> sequestration in coal seam or shale gas reservoirs are explained to illustrate how unconventional reservoir geomechanics can be extended to solve related and even more complex challenges combining both theoretical and practical models backed by data unconventional reservoir geomechanics gives reservoir engineers a smarter and more sophisticated tool to approach today's more complex geomechanical modeling challenges provides a foundation of solutions for the extraction of unconventional resources and other related areas introduces a completely new theoretical framework of coupled multi spatial and multi temporal multi physics in rocks with significant contrasts of physical properties among components focuses on understanding and inclusion of four characteristics of unconventional rocks with applications to areas such as shale gas coal seam and CO<sub>2</sub> sequestration

this thesis presents an important step towards a deeper understanding of naturally fractured carbonate reservoirs nfcrs it demonstrates the various kinds of discontinuities using geological evidence mathematical kinematics model and computed tomography and uses this as a basis for proposing a new classification for nfcrs additionally this study takes advantage of rock mechanics theory to illustrate how natural fractures can collapse due to fluid flow and pressure changes in the fractured media the explanations and mathematical modeling developed in this dissertation can be used as diagnostic tools to predict fluid velocity fluid flow tectonic fracture collapse pressure behavior during reservoir depleting considering stress sensitive and non stress sensitive with nonlinear terms in the diffusivity equation applied to nfcrs furthermore the book presents the description of real reservoirs with their field data as the principal goal in the mathematical description of the realistic phenomenology of nfcrs

course held May 19-20 2011 during the 2011 joint CSPG CSEG CWLS convention recovery energy environment economy

reservoir geomechanics investigates the implications of rock deformation strain localization and failure for completion and production of subsurface energy reservoirs for example effective hydraulic fracture placement and reservoir pressure management are among the most important applications for maximizing hydrocarbon production the correct use of these applications requires understanding the interaction of fluid flow and rock deformations in the past a considerable amount of effort has been made to describe the role of poroelastic and thermal effects in geomechanics however a number of chemical processes that commonly occur in reservoir engineering have been disregarded in reservoir geomechanics despite their significant effect on the mechanical behavior of rocks and therefore fluid flow this dissertation focuses on the mechanical effects of two particular chemical processes gas desorption from organic rich rocks and mineral dissolution in carbonate rich formations the methods employ a combination of laboratory studies field data analysis and numerical simulations at various length scales the following conclusions are

the results of this work 1 the introduced numerical model for fluid flow with effects of gas sorption and shear failure impaired permeability captures the complex permeability evolution during gas production in coal reservoirs the simulation results also indicate the presence non negligible sorption stresses in shale reservoirs 2 mineral dissolution of mineralized fractures similar to pore pressure depletion or thermal cooling heating can increase stress anisotropy which can reactivate critically oriented natural fractures in situ stress chemical manipulation can be used advantageously to enlarge the stimulated reservoir volume 3 semicircular bending experiments on acidized rock samples show that non planar fractures follow high porosity regions and large pores and that fracture toughness correlates well with local porosity numerical modeling based on the phase field approach shows that a direct relationship between fracture toughness and porosity permits replicating fracture stress intensity at initiation and non planar fracture propagation patterns observed in experiments and 4 numerical simulations based on a novel reactive fluid flow model coupled with geomechanics show that mineral dissolution i lower fracture breakdown pressure ii can bridge a transition from a toughness dominated regime to uncontrolled fracture propagation at constant injection pressures and iii can increase fracture complexity by facilitating propagation of stalled fracture branches the understanding of these chemo mechanical coupled processes is critical for safe and effective injection of  $\text{CO}_2$  and reactive fluids in the subsurface such as in hydraulic fracturing deep geothermal energy and carbon geological sequestration applications

the increasing demand for hydrocarbons and decreasing reserves have created the necessity to produce oil and gas more efficiently and economically increasingly oil and gas companies are focusing on unconventional hydrocarbons oil sands shales and cbm for this class of reservoir materials the geomechanical response of the reservoir can play an important role in the recovery process for naturally fractured stress sensitive reservoirs or thermal recovery processes geomechanical processes play an even greater role in efficient economic recovery for simulations of these processes most research efforts have been focused on reservoir geomechanical simulations using conventional reservoir simulators coupled to geomechanical codes while coupled reservoir geomechanics modeling has been recently widely studied in the literature there is no applicable methodology implemented or proposed to mitigate the challenging computational cost involved with the inclusion of geomechanics in large multimillion cell reservoirs past studies so far have focused on different coupling schemes but not on the efficient and robust simulation workflows this research was conducted with the aim of development and application of various different strategies to include geomechanics into reservoir simulation workflows in large scale reservoirs and in a timely fashion process the research was performed to allow the future simulators to perform high resolution reservoir geomechanical simulations in a large scale near field and far field with long simulation time windows and lowest computational cost initially analytical proxies were developed and recommending for implementation in lieu of complex reservoir simulations the analytical model was for prediction of heavy oil geomechanical responses everywhere in the reservoir the model adopted the use of the mathematical domain decomposition technique and a novel temperature front tracking developed in the very early stage of the research as opposed to classical analytical models the proxy predicted reservoir flow and mechanical behavior on a synthetic case geometry with real hydraulic data everywhere in the reservoir and in dynamic and transient flow regimes subsequent research was aimed at reservoir geomechanics coupled model order reduction by use of a numerical proxy the proxy took advantage of streamline linear space behavior and power in decomposition of the reservoir domain into sub systems delineation drainage areas the combination of localization and linearization allowed predicting both mechanical and fluid flow responses of the reservoir with only solving the pressure equation in cartesian underlying 3d grids and the solution of saturation transport equation along only one streamline following this a streamline based reservoir geomechanics coupling was proposed and was implemented within a fortran c based platform the new developed technique was compared in terms of computational cost and results accuracy with the conventional hydromechanical coupling strategy that was developed on a c based platform by use of collocated

fv fem discretization scheme one of the final stages of the research explored different streamline based reservoir geomechanics coupling strategies for full field reservoir simulations various coupling strategies including sequential coupling schemes and a semi fully coupling scheme to embed geomechanics into streamline simulation workflow was developed and performed numerical software with advanced gui was coded on qt programming language c based developed to couple mechanical simulator to streamline simulation engine while streamline simulations were the center of the research the last stage of research was conducted on numerical and physical stability convergence and material balance errors of sl based reservoir geomechanics class of couplings the results provided a solid foundation for proper selection of time steps in sl based coupling to ensure a numerically stable and physically robust hydromechanical simulation as a result we showed that use of streamline simulation in both proxy forms and simulator forms have significant added value in full field reservoir geomechanics simulations

petroleum engineers have a difficult time making the leap between theory of rock mechanics and practical applications surrounding petroleum geomechanics especially in more complex operations such as hydraulic fracturing applied petroleum geomechanics provides a bridge between theory and practice as a daily reference with direct industry application going beyond the basic fundamentals of rock properties this guide covers critical field and lab tests along with interpretations that follow within actual drilling operations and worldwide case studies including abnormal formation pressures from many major petroleum basins rounding out with borehole stability solutions and the geomechanics surrounding hydraulic fracturing and unconventional reservoirs applied petroleum geomechanics gives petroleum engineers a much needed resource to tackle today s advanced oil and gas operations understand a great wealth of methods in formation evaluation and the most recent advancements in the area including tools techniques and success stories bridge the gap between theory of rock mechanics and practical oil and gas applications learn pore pressure calculations and predictions critical to shale and hydraulic activity

through past years the importance of geomechanics in oil and gas industry has been recognized and taken into consideration geomechanical studies have attracted the attention of researchers in petroleum engineering field due to its effects on problems which arise frequently in oilfields such as wellbore stability sand production and caprock integrity caprock integrity can be taken into account as a critical issue during gas injection into gas cap high injection rates may result in significant increases in pressure and cause reactivation of caprock fractures and faults in worst scenario the high injection pressure induces and propagates new fractures in this research the effect of geomechanics is included through the derivation of equations related to fluid flow through porous media partial differential equations pdes which govern the fluid flow and geomechanical effects are discretized by using finite element method fem regarding location and finite difference method fdm regarding time the coupled partial differential equations pdes are solved by using a modified matlab code in order to determine the pore pressure displacement porosity and permeability distribution a pressure maintenance method including geomechanics effect is also developed by eclipse reservoir simulator furthermore the rock properties such as young s modulus poisson s ratio and the strength properties are determined by utilizing triaxial test on anhydrite caprock and limestone reservoir rock for samples of kurdistan region near koya city after running the matlab code it was found that the pore pressure increases during the experiment while displacement porosity and permeability decreases due to the stress which is applied on the core plug from the simulation results it was found that the fault withstands less pressure and stress than other parts of the reservoir which leads to fault failure the results of the simulation determine that the gas injection rate of 5000 mscf day is the rate at which the fault failure occurs due to permeability increase in the fault after stress modification gas saturation alteration in the caprock layer of the model is an indicator of caprock failure in addition from triaxial test results it is noticed that the strength of anhydrite caprock is more than the limestone reservoir rock the young s modulus value which ranges between 45 4 41 9 gpa for anhydrite caprock and 9 16 13 05 gpa for limestone reservoir rock indicate higher strength of caprock than reservoir rock in other words the

integrity of the caprock is guaranteed for higher injection rates without the fault existence the results from the matlab code eclipse reservoir simulator and triaxial test approve the effect of pressure alteration due to pressure maintenance performance on the fault activation and later on the caprock integrity failure

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