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Unlocking the Unconventional Oil and Gas Reservoirs: The Effect of Laminated Heterogeneity in Wellbore Stability and Completion of Tight Gas Shale Reservoirs

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Abstract

Unconventional shale-gas reservoirs are complex systems with predominant layered heterogeneity. This results in high variability in material properties and in considerable contrast in mechanical and elastic properties along orientations parallel and perpendicular to bedding. Understanding the effect of this variability in strength and elastic properties with bed orientation, to hydraulic fracturing breakdown pressures, height containment, and long-term stability of wellbores and perforations, are of highest interest to unconventional, shale gas, reservoir applications. Successful hydraulic fracturing is fundamental for economic production from nano-darcy permeability gas shales. By incorporating anisotropic elastic deformation, to better represent the behavior of unconventional tight gas reservoirs, we facilitate the understanding of near-wellbore stress concentrations and their effect on fracture initiation. Results show that strong elastic anisotropy results in lower breakdown pressures and lower tortuosity at the wellbore face. As a consequence, selecting perforating intervals along sections with highest elastic anisotropy minimize fracture initiation problems, and results in lower treating pressures. In addition, elastic anisotropic behavior influences the magnitude of the minimum horizontal stress and the potential for fracture containment. Traditional isotropic-rock models do not capture this behavior. When applied in anisotropic formations these models misrepresent the potential of fracture containment. This leads to erroneous selections of perforation intervals (vertical completion) or landing depths of horizontal wellbores. A third consequence of strength and elastic anisotropy is the high risk of wellbore stability during drilling. In rocks with changing elastic moduli and strength with bed orientation, the highest risk of wellbore failure often occurs during building angle from the vertical to the horizontal directions. Along this path, there is a critical angle, defined by the strength anisotropy of the rock that will maximize the risk of failure. Minimizing this risk, e.g., by controlling the mud weight or well inclination, is of principal importance to the economic success of the play. In this paper we conduct numerical simulations on unconventional gas shales, exhibiting moderate to strong elastic and strength anisotropy, to evaluate the effect of their anisotropic behavior on well construction and completion. We also show that traditional isotropic models may lead to erroneous completion decisions, and underestimating the risk of wellbore failure. We conclude by suggesting that modeling and predicting near-wellbore effects of horizontal completions and wellbore stability in anisotropic shales is straightforward, provided that appropriate measurements of anisotropic strength and elastic properties are obtained on each of the various lithofacies present in the system.

Introduction

Materials with different properties along different regions of their body are called heterogeneous. Their heterogeneity may be random or organized. Layered media are examples of materials with organized heterogeneity that exhibit similar properties within a bed plane and different properties along different beds. These types of materials may be modeled by assuming rotational symmetry in material properties, with an axis of rotation perpendicular to bedding¹. Because of their laminated texture (which could be fine-scale in shales, or larger-scale in reservoir interbeds) their elastic moduli and strength, change with orientation to bedding. In general, bedded materials tend to be stiffer along the direction parallel to bedding and more compliant along the direction perpendicular to bedding. They are also weaker in tension along a direction

¹ For petroleum related rocks, it is typical to assume that the direction of rotational symmetry coincide with the direction perpendicular to bedding. This assumption is a good approximation except when the material texture is complicated; for example, textures exhibiting inclusions, and discontinuous or non-parallel beds.