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Effect of Rock Physical and Mechanical Properties on In Situ Stress in Carbonate Reservoirs

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There is ample evidence showing that in situ stress state in the Earth's crust interacts with heterogeneity in rock mass, for instance, due to the presence of natural discontinuities (such as faults and fractures) and variation of rock physical/mechanical properties. In the present study, we show that such an interaction is substantial in carbonate reservoirs where heterogeneity in rock properties is especially profound. In situ stress is normally expressed in terms of the orientations and magnitudes of the three principal stresses. We first estimate in situ stress orientations using drilling-induced borehole stress indicators such as borehole breakouts and drilling-induced tensile fractures (DITFs) observed in several boreholes in carbonate reservoirs in Middle East. The stress indicators show a significant rotation of the maximum horizontal principal stress (SHmax) azimuth as much as 60° within a depth interval of 500 m. We note that there is a remarkable difference in SHmax azimuth between relatively stiff layers exhibiting high Young's moduli and soft layers having low Young's moduli. To explain the observed rotation of stress orientation depending on the rock property, we employ the concept of residual stress, which remains in rocks from the past. We assume that the orientation of the residual stress in this reservoir is that prevailed in late Tertiary and that its magnitudes vary from layer to layer depending on elastic properties of individual layers. By superposing two stress fields that prevail respectively in the present-day and the past, we find the resulting stress field that is good agreement with the observed stress orientation. Secondly, we estimate in situ stress magnitudes using some geomechanical analyses based on borehole breakout width and the presence of DITFs. A notable aspect is that the magnitude of horizontal principal stress vary widely such that its gradient with depth increases with Young's modulus. The increase of stress gradient with Young's modulus is almost monotonic, suggesting that the mechanical property of individual layers has a significant effect on stress transfer through the reservoir. This result indicates that a stiffer rock conveys a higher magnitude of stress, and that there is a strong interplay between in situ stress and the heterogeneity in rock mechanical properties. Implications provided by our study can be useful for various aspects in petroleum development, such as wellbore stability and hydraulic fracturing design.