Using borehole breakouts to constrain the complete stress tensor: Results from the Sijan Deep Drilling Project and offshore Santa Maria Basin, California

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Abstract. We use borehole breakouts in nonvertical drill holes to constrain the directions of the three principal stresses and their relative magnitudes. In this paper we start by modifying previously published breakout selection criteria to work with highly deviated borehole data. We present a forward modeling technique using genetic algorithms and a nongradient N-dimensional optimizer to find the best fitting stress state for a set of breakout data. The stress state is parameterized by three Euler angles and the stress state ratio ϕ. A technique is developed to determine the 95% confidence weighted misfit between a model and the data. We then map out the 95% misfit confidence limits on the best fitting stress state. This technique is applied to data published by *Qian and Pedersen* [1991]. Removing their constraint of a vertical principal stress direction reduces the misfit between the stress state and the breakout data. We find that the best fitting stress state they report with a vertical principal stress direction lies outside our 95% confidence limits. We also invert breakouts in the offshore Santa Maria Basin, California. These data show a "thrust faulting" stress state with the maximum principal stress, S_1, at N148.5°E plunging 31.5°. The 95% confidence range for the azimuth of S_1 ranges from N143.0°E to N198.1°E. The stress ratio ϕ was found to be $0.821^{1}_{0.584}$.

Introduction

Stress-induced borehole breakouts, observed on four- and six-arm dipmeter logs or acoustic televiewer logs from drill holes, are shear failures of the borehole wall that form centered at the azimuth of greatest compressive stress at the borehole wall, provided that this compressive stress exceeds the rock strength. If the borehole is vertical and aligned parallel to one of the principal stress axes, the breakouts will form at the azimuth of the far-field least horizontal principal stress, S_h. The orientation of borehole breakouts thus constrains the directions of the horizontal principal stresses S_h and S_H. Breakout analyses in vertical holes are commonly used to determine the directions of the principal horizontal stresses, under the assumption that one of the principal stresses is vertical (S_v). The results have been shown to be consistent with other indicators of stress direction, such as hydraulic fractures, earthquake focal mechanisms, and overcoring measurements, on both local and regional scales [e.g., *Bell and Gough*, 1979, 1983; *Zoback and Zoback*, 1980; *Gough and Bell*, 1981; *Plumb and Hickman*, 1985; *Stock et al.*, 1985; *Zoback et al.*, 1989; *Zoback and Healy*, 1992; *Zoback*, 1992].

Commonly, breakout data are used to constrain directions of stress but not their relative magnitudes. However, in principle, breakouts can yield information on stress magnitudes, both because the presence of a breakout indicates that the hoop stress exceeds the yield strength of the rock and because, when the borehole is not aligned with a principal stress axis, the breakout orientation depends on the relative magnitudes of all three principal stresses, as well as on the orientations of the stresses. Thus additional information about the stress tensor can be obtained from the directions of breakouts in deviated (nonvertical) drill holes; one can estimate the directions of all three principal stresses and provide