Wellbore Breakouts in Sandstones

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Laboratory-scale drilling tests in ten porous sandstones subjected to true triaxial stress conditions ($\sigma_H \neq \sigma_h \neq \sigma_v$) throw new light on the mechanics of failure that results in borehole breakouts. Three of the sandstones (Kyune, n (porosity)=16%; Berea, n=17%; and Tablerock, n=30%) are limited to 55 to 75% quartz grains, and contain sizable amounts of feldspar, clay minerals and iron oxide. These sandstones (denoted here as class I) are generally well cemented, and have poor grain sphericity. At critical far-field stress conditions they develop 'dog ear' or V-shaped wellbore breakouts at diametrically opposed wall locations aligned with the direction of the least horizontal stress σ_h, where the highest compressive stress concentration occurs. Optical and scanning electron microscope analyses of the zone immediately ahead of the breakout tip reveals that dog-ear breakouts occur as a result of dilatant inter- and intra-granular multiple microcracking subparallel to σ_H, a process similar to that observed in crystalline and hard carbonate rocks. The microcracks create clusters of thin parallel layers of rock that are too slender to sustain the concentrated tangential stress. They buckle, and are ejected in succession into the borehole, forming the breakout. No localized deformation ahead of the breakout tip is observed.

The other six sandstones (St. Peter n=12-20%; Mansfield n=26%; Aztec n=26%; high-porosity variety of Berea n=25%; St. Meinrad n=28%; and Coconino n=20%) are distinguished by their mineral composition (predominantly quartz at 87%-99%, with some feldspar, and very little clay or iron rich minerals). Common to all six rocks is the intergranular contact bonding, which is primarily through suturing, with very little clay or iron oxide cementation. These Class II sandstones yield breakouts of a drastically different shape: very narrow, long, and tabular slots that resemble fractures. These 'fractures', however, extend counterintuitively at right angles to the largest horizontal stress σ_H direction. Typical class II sandstones are of Aeolian origin. Nucleation and propagation of the slot-like breakout are localized along the plane where the highest tangential stress concentrates. SEM analysis of horizontal cross sections ahead of the breakout tip revealed a long band as narrow as the breakout, exhibiting reduced porosity, indicative of compaction. The resemblance to field "compaction bands" observed by Mollema and Antonellini (1996) is remarkable. Within the laboratory-developed band most grains are still intact, but some grain splitting and crushing is also visible. The band is only several grains wide, and is perpendicular to the maximum stress. A direct comparison between SEM images of field and laboratory-induced compaction bands in Aztec sandstone suggests that the two have similar characteristics, although the field bands have a lower porosity. The initiation of the compaction bands along the σ_h springline results from the high stress concentration relative to grain bonding strength. Thus, slot-shaped breakouts in quartz-rich, high porosity sandstones appear to be compaction bands that have been emptied. The emptying of the debonded grains within the compaction bands is facilitated by the drilling fluid that flushes off loose grains within the band.

Tests at the University of Wisconsin indicate that the mechanism of slot breakout failure appears to begin with the debonding of grains within the very narrow band perpendicular to σ_H, where the maximum stress concentration occurs. This brings about the compaction of the debonded grains, and the splitting of some. Loose grains at the borehole wall are flushed out and that precipitates a sequential loosening of grains and their ejection into the borehole, assisted by the circulating drilling fluid. As the breakout tip advances, the stress concentration ahead of it persists, extending the apparent compaction band, which in turn leads to additional grain expulsion and breakout lengthening. Stabilization may occur as soon as fluid circulation stops or is significantly reduced as the drilling bit advances, and the breakout tip is farther away from it. It is also possible that grains at the breakout tip become so well wedged that they create a stable arch, stopping any additional grain expulsion.

The process of slot breakout formation is the consequence of a failure mode hitherto unrecognized. The created breakout slot has the appearance of a mode I tensile crack, except it is the result of high compressive (rather than tensile) stress acting across it. The failure mechanism leading to dog-ear breakouts in class I sandstones is clearly dilatant, by which rock volume increases resulting from extensile and/or shear cracking. In class II sandstones we detect what could be defined as an anti-dilatant failure mechanism, in which the volume of the failed zone (the compaction band) actually undergoes contraction.

It is envisaged that in field situations this process may continue for a substantial distance (at least several times the wellbore diameter), potentially leading to considerable sand production. Unfortunately, slot breakouts have not been observed in the field because available geophysical logging tools have not been designed to detect narrow slots beyond a few centimeters from the borehole wall.