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Selection of failure criteria for estimation of safe mud weights in a tight gas sand reservoir

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ABSTRACT

In an undisturbed state, a stress field present in the earth consists of virgin stress in the rock. A change in this stress occurs due to drilling the borehole and disturbing the original stress by either introducing drilling fluids or by getting reservoir flow in the borehole. This change in stress leads to a classical problem of well bore instability. To resolve wellbore instability, evaluation of rock mechanical properties and in-situ stresses is essential. The output of this study is evaluation of safe mud weights which is critical to safe drilling. If the mud weight used for drilling is higher than those predicted by the failure criteria, the mud percolates into the formation, causing tensile failure (fracture stress) which induces fluid losses. Conversely, the lower mud weight results in shear failure (collapse stress) of rock leading to borehole breakout and collapse of wellbore. Three types of failure criteria i.e. Mohr-Coulomb, Mogi-Coulomb and Modified Lade are considered in this study. The stress around the wellbore is obtained using Kirsch equation. The input parameters required for estimating the safe mud weights from these failure criteria are rock mechanical properties, friction angle and cohesion which are estimated from well log data. The rock mechanical properties like Poisson's ratio and Uniaxial Compressive Strength are computed using sonic derived compressional and shear velocities. Internal friction angle is obtained using gamma ray log and is validated with core data before it is used in further analysis. The failure criteria have been applied to two wells located in a field in Gulf of Oman. The analyses show that the Mohr-Coulomb overestimates the mud weight while the Modified Lade criterion underestimates it. The result for a tight gas sand reservoir suggests that the Mogi-Coulomb predicts better mud weight values that are in agreement to those measured values chosen for drilling.

1. Introduction

Borehole instabilities during drilling may cause substantial problems. A borehole stability problem is an example of what drillers refer to as a “tight hole” or “stuck pipe” incident. There are a variety of reasons for getting a tight hole or stuck pipe scenario but in a large number of cases, the primary cause is the failure of the borehole.[1,2] When a well is drilled, the surrounding rock gets disturbed. The disturbed rock sometimes unable to support the load previously burdened by the removed rock and this causes the stress concentration near the borehole that may lead to formation failure.[3,4] Shaly layers increase the chance of bore instability in a reservoir or in the overburden strata. These problems not only add to the drilling costs during exploration and production phases but also lead to the rig time loss and the loss of tool string in the hole in many cases. In recent years with increasing complexity of drilled wells to access more difficult reservoirs, new challenges have come up, making the stability issue more critical to handle. This warrants the need to work towards resolving this complex problem.

In the past couple of decades, the reservoir types have also changed and shifted from conventional clastic-carbonate type reservoir to tight shale, tight sand reservoir types which are challenging to drill because of its complex nature of stress, lithology and petrophysical property. Thus, there is a growing need to evaluate for an optimum mud weight to prevent possible instability issues, which requires the study of failure criteria on a case-by-case basis. Among the number of failure criteria used in the industry, an attempt is made in this paper to evaluate the relative efficacy of three failure criteria - Mohr-Coulomb (1776), Mogi-Coulomb (1971) and Modified Lade (1999) in light to estimating the safe mud weights (Section 6). The input parameters required for estimation of safe mud weights are described and estimated in Sections 3, 4 and 5. The well log data from a tight gas sand reservoir in Gulf of Oman oil are described in the study area (Section 2). The paper concludes with discussions on the obtained results and reiteration of the choice of an

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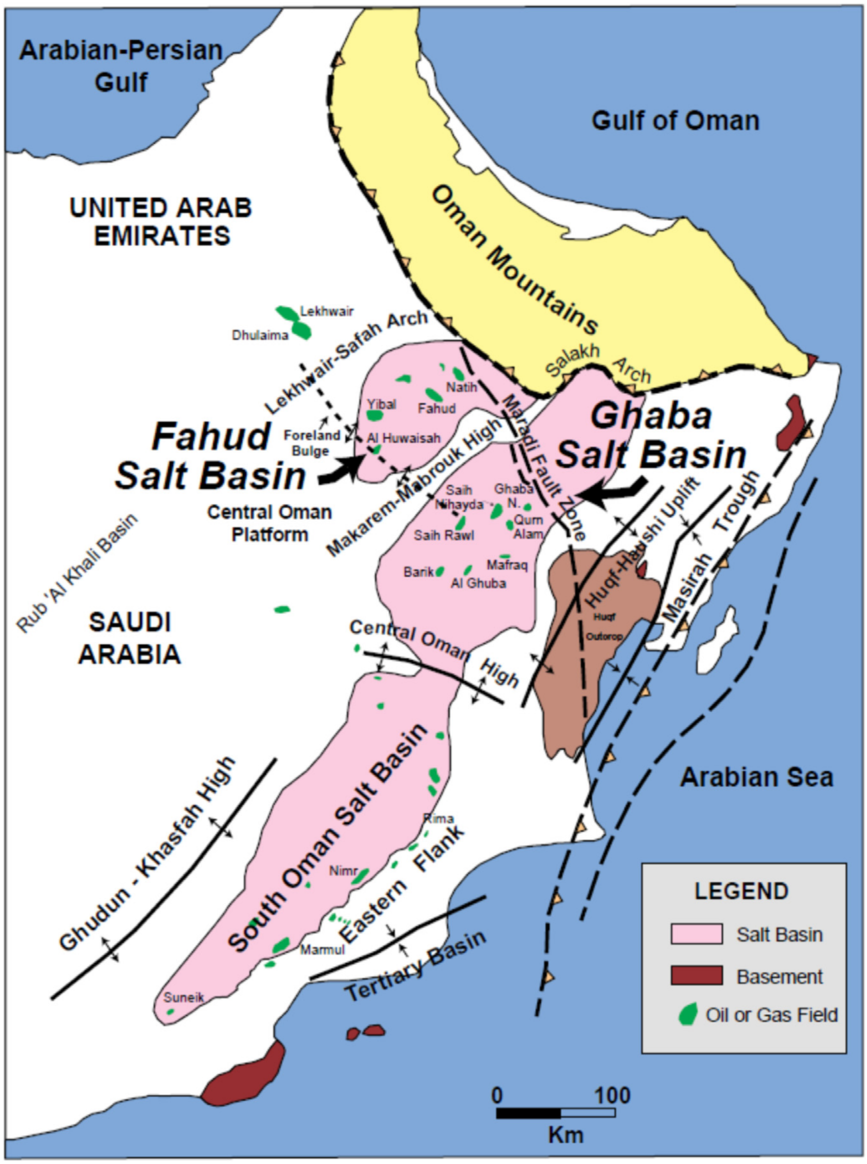

Fig. 1. Onshore petroleum fields of Oman[19].

appropriate failure criteria for calculating safe mud weights.

2. The study area

The study area is an oil field in Gulf of Oman. For confidentiality reasons, the location of the field is not disclosed here. The field is a faulted anticline, developed above a large Precambrian to Early Cambrian extensional fault block (Fig. 1). This structure was progressively developed through the Pre-Cambrian to Lower Palaeozoic and has been repeatedly reactivated throughout the Mesozoic and Cenozoic periods. The Sandstone members comprise a variety of reservoir facies within an overall continental braid-plain to marginal marine/offshore setting.

There are two onshore wells: Well-1 and Well-2, taken for study. The well data available for analysis are gamma ray, density, compressional and shear sonic logs from two wells. The responses of these two wells are shown in Figs. 2 and 3. The Calliper log is represented by CALI, the Gamma ray log by GR, the density log by RHOB, the Compressional log by DTCO and the shear sonic log by DTSM transit time. The lithologies encountered in both wells are primarily sand, shale, silty sand and alteration of sand and shale.

3. Estimation of rock properties

The rock properties which includes density, composition, acoustic velocity, Poisson's ratio (PR), uniaxial compressive strength (UCS), internal frictional angle (ϕ), cohesion (cs) are computed from the well log data using the standard empirical relationships.[5–8] The Gamma ray (GR), density, sonic compressional transit time (DTCO) and sonic shear transit time (DTSM) logs are used for estimation of rock properties. PR and UCS are derived from sonic log and calibrated with the core data. The empirical relations for computing internal friction angle (ϕ) and uniaxial compressive strength (UCS) are given by.[6,8]

Eq. (1) calculates the internal frictional angle for both wells 1 and 2. The values for μ_{shale} and sand has been assumed as 0.5 and 0.9 respectively.[7] The maximum value of GR for shale and the minimum value for sand have been analysed from log data (Figs. 2 and 3).

$$\phi = tan^{-1}\frac{(GR - GR_{sand})\mu_{shale} + (GR_{shale} - GR)\mu_{sand}}{(GR_{shale} - GR_{sand})} \tag{1}$$

UCS for sandstone is calculated from Eq. (2),[9]

$$UCS = 1277e^{-0.037D_t} \tag{2}$$