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HIGH HORIZONTAL STRESS IN THE VISUND FIELD, NORWEGIAN NORTH SEA: CONSEQUENCES FOR BOREHOLE STABILITY AND SAND PRODUCTION

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Abstract

We examine drilling-induced tensile fractures in five vertical and inclined exploration wells in the Visund oil field in the northern North Sea. Each well yields a consistent azimuth of the maximum horizontal stress both laterally and with depth.

The magnitudes of the three principal stresses (S_v, S_{hmin}, and S_{Hmax}) are consistent with depth and reflect a strike-slip faulting stress regime. The magnitude of the maximum horizontal stress is significantly higher than the vertical ($S_{Hmax} \approx 1.3\ S_v$) and minimum horizontal stresses in our models.

We determine optimally stable trajectories for borehole stability during drilling, after the completion of drilling, and for preventing sand production after reservoir pore pressure drawdown.

Introduction

Determination of the full stress tensor in oil fields is critical for addressing engineering problems of borehole stability and sand production as well as geologic problems such as understanding dynamic constraints on hydrocarbon migration and fracture permeability. Controlling wellbore instabilities requires understanding of the interaction between the rock strength and in-situ stress. Because the in-situ stress and rock strength cannot be altered or controlled, the only way to inhibit borehole failure during drilling is to adjust engineering practice by choosing optimal trajectories and mud weights. Similarly, utilization of an appropriate trajectory can limit sand production by reducing the tendency for failure around a wellbore. This paper presents an analysis of stress and borehole stability in the Visund field, which is located in the Norwegian North Sea to the northwest of Bergen (**Fig. 1**).

The state of stress in the Norwegian North Sea is generally characterized by an east-west to northwest-southeast compression, but exhibits appreciable scatter in places[1,2,3,4]. Scatter in the orientation of wellbore elongations observed in the northern North Sea has led some investigators to claim that shallow stress directions are decoupled from the deeper regional stress field[5]. We show that the orientation of the stress tensor can be reliably constrained and that it is consistently oriented throughout the thickness of the brittle crust.

Those studies that have attempted to constrain the magnitudes of all three principal stresses[5,6] have published relative magnitudes of the stresses that are inconsistent with the strike-slip to reverse faulting stress field seen from earthquake focal plane mechanisms[7]. In the following sections we describe how observations of drilling-induced compressive failures[8,9,10] and wellbore tensile failures[11,12,13] can be integrated with other routinely available wellbore information to reliably constrain the full stress tensor. Our approach follows the integrated stress measurement strategy (ISMS), outlined by Zoback et al.[14] and Brudy et al.[15], to constrain the magnitudes and orientations of all three principal stresses. Using our estimates of in-situ stress we estimate bounds on the effective rock strength. This information is then used to determine optimally-stable trajectories for drilling and minimizing sand production.

Observations of Wellbore Failure

Examination of Formation MicroScanner/Formation MicroImager (FMS/FMI)[16] logs run in seven wells revealed extensive drilling-induced tensile failures in five of the wells. An example of this data can be seen in **Fig. 2**.

All wells except 10S were drilled nearly vertically to total depth. Near-axial tensile fractures observed in wells 6, 7, 8, and 11, as well as in the vertical portion of 10S, suggest that the vertical stress is a principal stress in this field[13]. **Fig. 3** summarizes our findings concerning the orientation of the maximum horizontal stress. The mean orientation of S_{Hmax} for each well is plotted in map view and clearly shows a consistently oriented stress field. The rose diagram shows the orientations of all of the tensile fractures from all of the wells. The plot in the lower right shows the depths over which the orientation of S_{Hmax} is constrained in each well. Gray shaded regions show portions of each well that were not logged. This

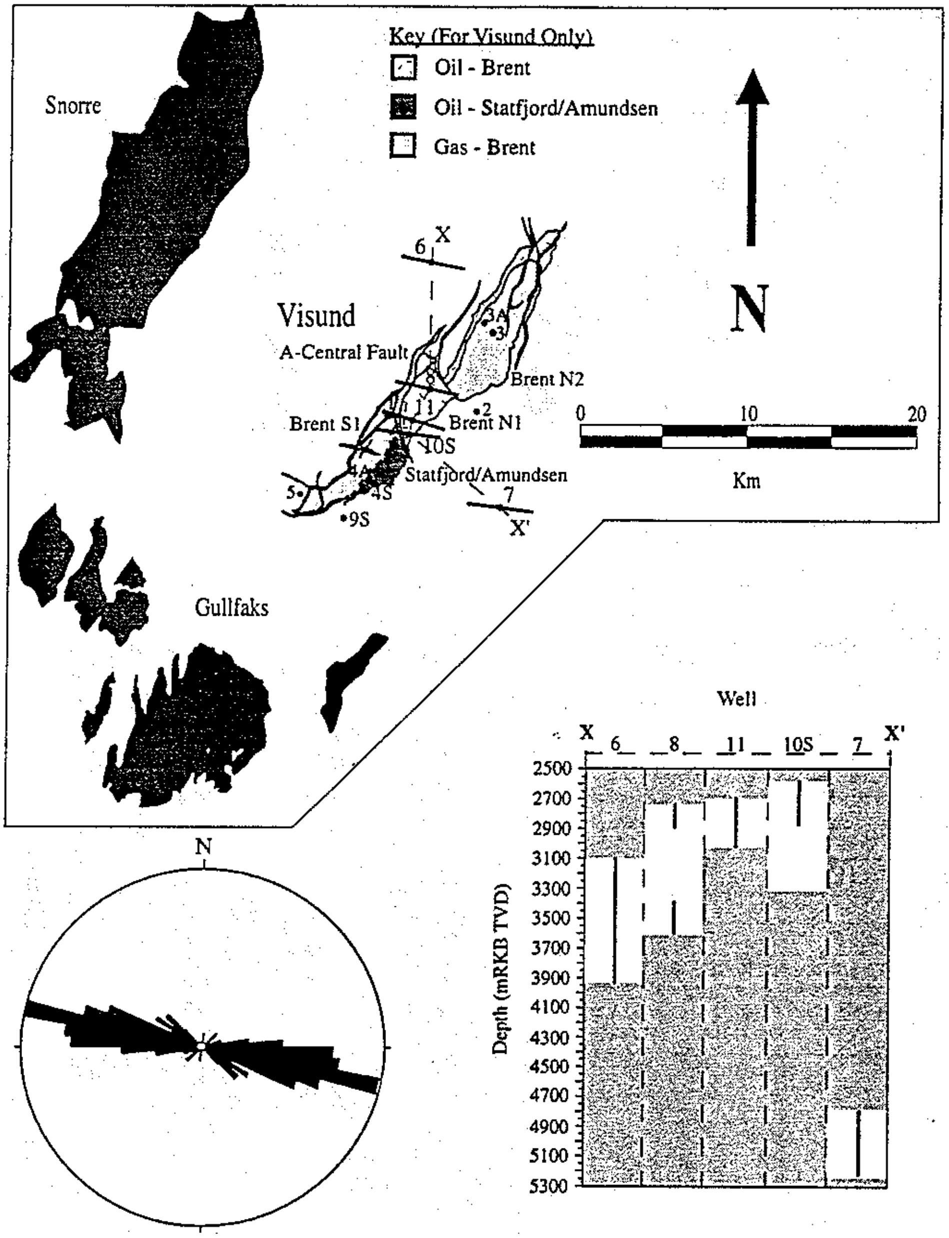
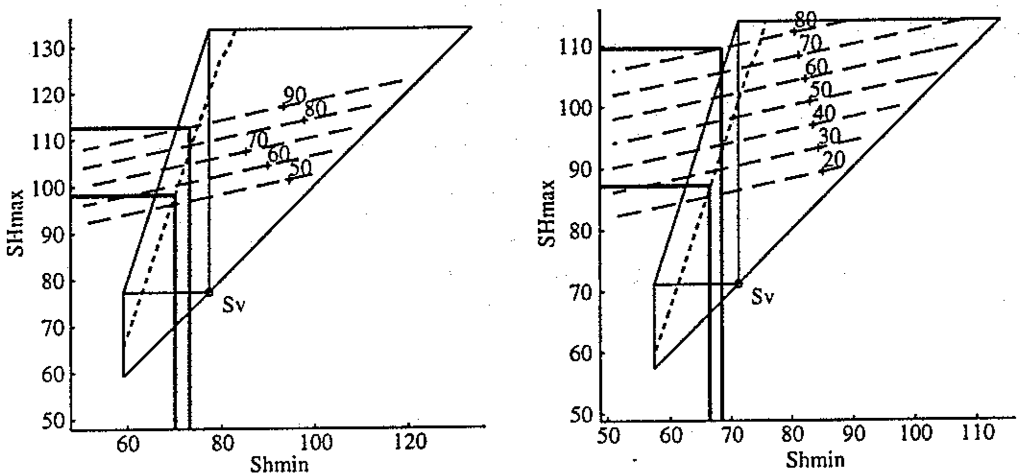


Fig. 3—Map view of S_{Hmax} orientations, rose plot with all of the orientation data, and plot showing the depths over which S_{Hmax} is constrained in each well. The gray regions show portions of the wells that were not logged. The orientation of the maximum horizontal stress is consistent both laterally and with depth in this field.

Well 6 - 3720 mTVD

Well 8 - 3560 mTVD

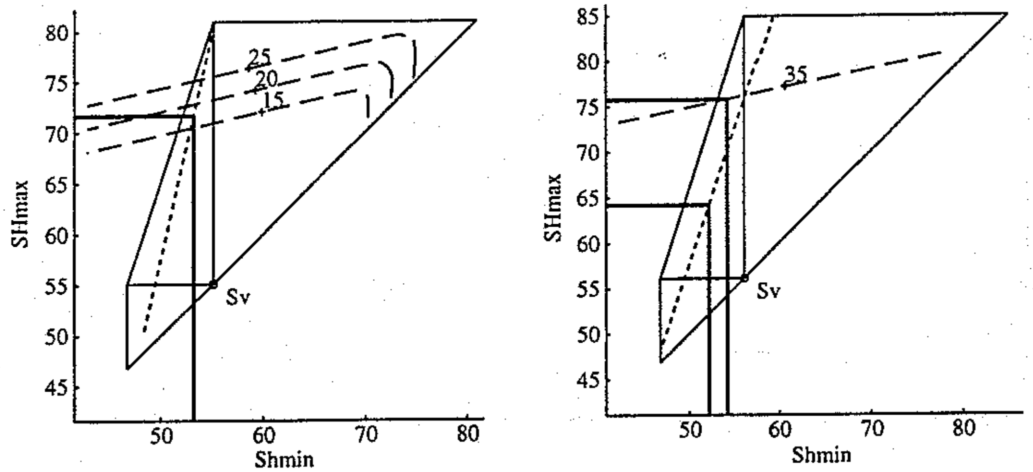


Sv = 77.3 Shmin = 71.5 Pp = 50.7 Pm = 58.3

Sv = 71.2 Shmin = 67.5 Pp = 51 Pm = 59.3

Well 10S - 2830 mTVD

Well 11 - 2850 mTVD



Sv = 55.1 Shmin = 53.2 Pp = 42.9 Pm = 49

Sv = 56.1 Shmin = 53.2 Pp = 42.5 Pm = 48.6

Fig. 4–Stress polygons showing the modeled values of the maximum horizontal stress in each of the wells. Each model is developed for a specific depth shown above the model. The relevant stress inputs (in MPa) are shown below the models. Tensile failure contours are shown with short dashes, and breakout contours are shown with long dashes. Each breakout line represents a different rock strength value, as shown, assuming that a breakout width of at least 40° would be required in order to be detected by the wide pads of the FMI tool.

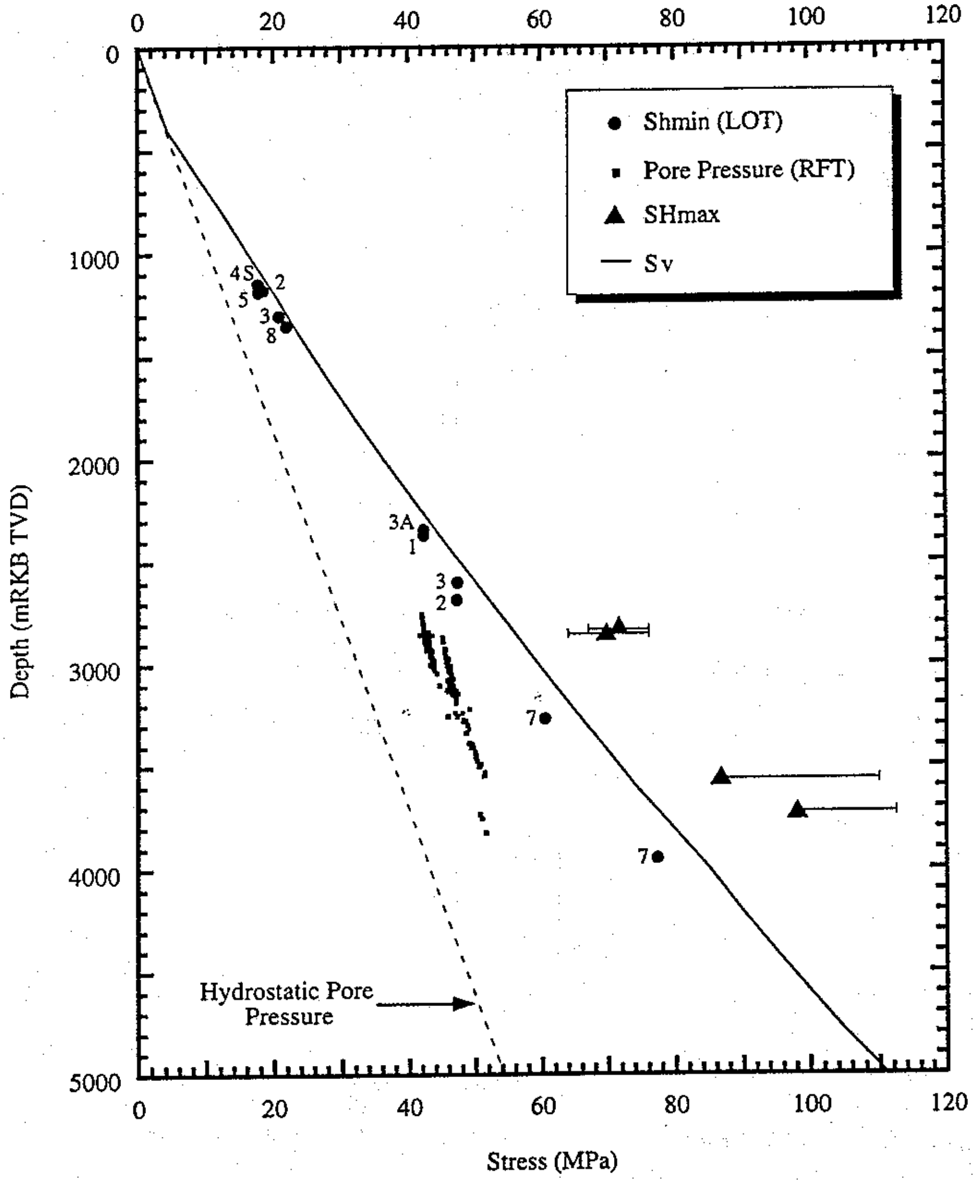


Fig. 5–Stress vs. Depth in Visund. Each stress point in this plot is derived as strictly as possible from the most reliable data in the field. Each leak-off test data point shows the well in which the test was run.

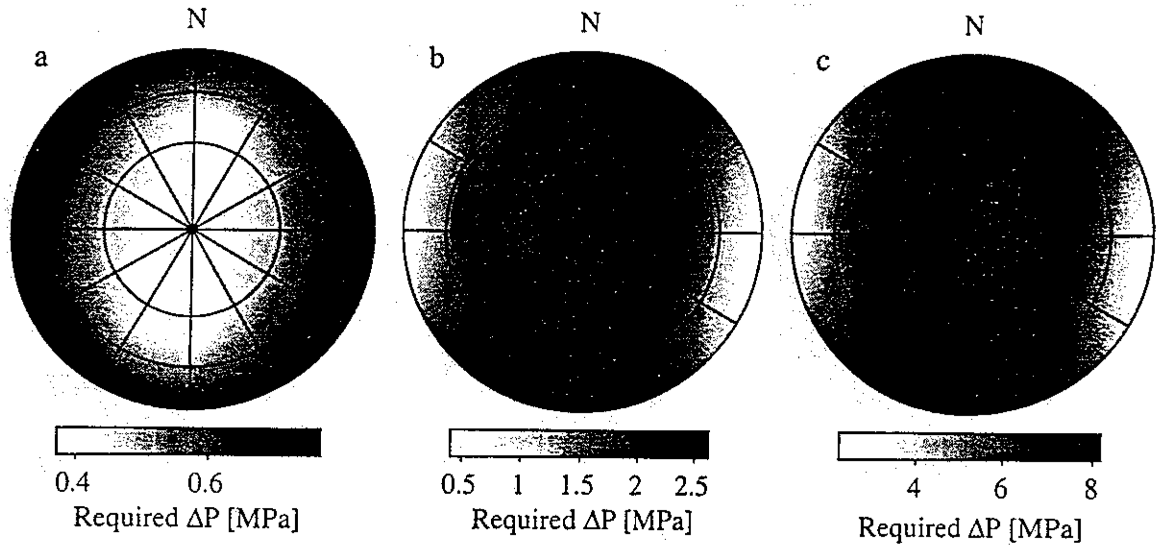


Fig. 6–Stereonets showing the required fluid pressure difference for preventing compressive failures from growing beyond 40° in width in rock with 20 MPa uniaxial compressive strength. a) Normal faulting stress state with nearly isotropic stresses. b) Strike-slip faulting stress state with moderate horizontal stress anisotropy. c) Strike-slip faulting stress state with high horizontal stress anisotropy.

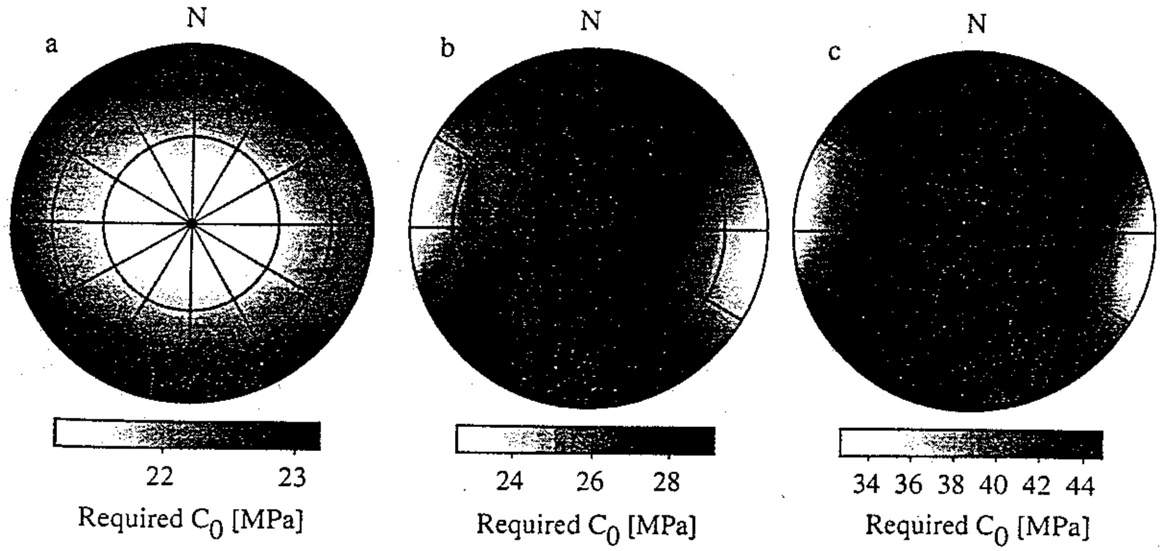


Fig. 7–Stereonets showing the compressive rock strength needed to prevent breakouts from growing beyond 90° in width in boreholes with ΔP = 0. a) Normal faulting stress state with nearly isotropic stresses. b) Strike-slip faulting stress state with moderate horizontal stress anisotropy. c) Strike-slip faulting stress state with high horizontal stress anisotropy.

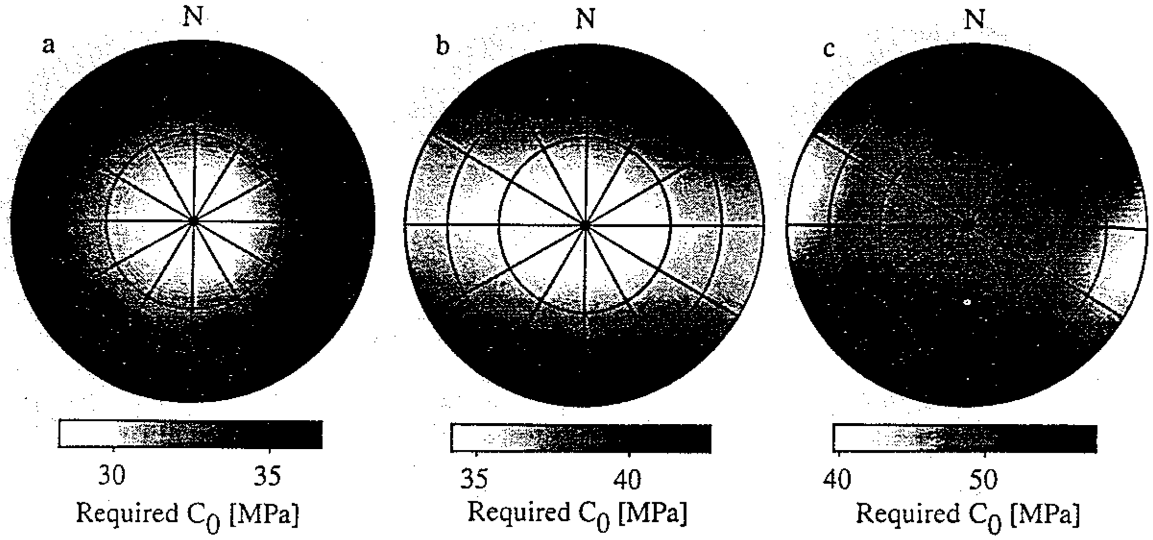


Fig. 8–Stereonets showing the compressive rock strength needed to prevent breakouts from growing beyond 90° in width in boreholes drilled into a reservoir with 10 MPa pore pressure drawdown. a) Normal faulting stress state with nearly isotropic horizontal stresses. b) Normal faulting stress state created from a strike-slip stress state and pore pressure drawdown. c) strike-slip faulting stress state.