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Transverse drilling-induced tensile fractures in the West Tuna area, Gippsland Basin, Australia: implications for the in situ stress regime

E.J. Nelson[a,*], J.J. Meyer[b], R.R. Hillis[a], S.D. Mildren[b]

[a]*Australian School of Petroleum, The University of Adelaide, Santos Petroleum Engineering Building, South Australia, Australia*
[b]*JRS Petroleum Research, Adelaide, Australia*

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Abstract

Drilling-induced tensile fractures (DITFs) have been interpreted on image logs from vertical wells in the Gippsland Basin, offshore southeastern Australia. Interpreted axial (vertical) DITFs have previously been well described worldwide. We also interpret transverse (horizontal) DITFs, which are horizontal fractures that are electrically conductive, non-planar, bimodal and constrained to the tensile region of the wellbore.

Elasticity theory predicts formation of both transverse and axial drilling-induced tensile fractures (DITFs) in vertical wells depending on the magnitude of the principal in situ stresses, pore-pressure and mudweight. Drilling-induced tensile fractures initiate in very specific stress environments. Axial DITFs can closely constrain a lower bound to the maximum horizontal stress ($S_{\mathrm{H\,max}}$) magnitude where the minimum horizontal ($S_{\mathrm{h\,min}}$) stress is known. If transverse DITFs are observed, they can constrain a lower bound to maximum and minimum horizontal stress magnitudes. The observation of transverse DITFs on image logs can constrain the stress field to one on the border of strike-slip and reverse faulting ($S_{\mathrm{H\,max}} \gg S_{\mathrm{h\,min}} \sim S_{\mathrm{v}}$) without requiring knowledge of the $S_{\mathrm{h\,min}}$ or $S_{\mathrm{H\,max}}$ magnitude. The observation of transverse DITFs in the West Tuna area combined with wireline log data, leak-off tests and pore pressure data are used to constrain the in situ stress tensor. The interpreted in situ stress tensor lies on the border of a strike-slip and reverse faulting regime ($S_{\mathrm{H\,max}} \sim 40.5\,\mathrm{MPa/km} > S_{\mathrm{h\,min}} \approx S_{\mathrm{v}} \sim 21\,\mathrm{MPa/km}$). Interpreted data from leak-off tests in the West Tuna area confirm that $S_{\mathrm{h\,min}} \sim S_{\mathrm{v}}$.

Keywords: Drilling induced tensile fractures; In situ stress; Gippsland Basin

1. Introduction

Accurate knowledge of the in situ stress tensor is critical to the efficient development of petroleum provinces, mineral resources and underground excavations. The in situ stress tensor has applications to petroleum and geothermal well design including the assessment of wellbore stability and the design of fracture stimulation and waterflooding programs. Similarly, knowledge of the in situ stress tensor is critical to civil and mining engineering problems such as stability of underground excavations (tunnels, mines, shafts, stopes), disposal of radioactive waste, drilling and blasting, and design of support structures. The magnitude of the maximum horizontal stress ($S_{\mathrm{H\,max}}$) is commonly the most difficult aspect of the in situ stress tensor to constrain [1]. It can be determined where breakouts or drilling-induced tensile fractures (DITFs) are observed on image logs and where rock strength is known [2,3]. Occurrences of DITFs that propagate axially or are inclined to a vertical wellbore have been well documented and are used routinely to constrain $S_{\mathrm{H\,max}}$ [3–8].

Analysis of image logs from two wells in the West Tuna area of the Gippsland Basin revealed fractures

*Corresponding author. Tel.: +61 8 8303 4308; fax: +61 8 8303 4345.
E-mail address: enelson@asp.adelaide.edu.au (E.J. Nelson).

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that were approximately horizontal (transverse to the wellbore axis) in orientation, non-planar and restricted in occurrence to the tensile region of the wellbore. The character and morphology of the fractures suggest that they may be drilling-induced, stress-related features rather than horizontal natural fractures.

The TDITFs presented herein are very similar to horizontal fractures described by Morin and Flamand [9] in image logs from the eastern equatorial Pacific. However, these authors describe the fractures as being induced by thermal stresses due to circulation of cold seawater against hot rocks. We believe that the TDITFs in West Tuna form in response to stress perturbation at the wellbore wall caused by high horizontal stresses in West Tuna. Elasticity theory is used herein to show that DITFs can form axially or transversely to a vertical well, depending on the in situ stress regime, rock strength and mudweight. Furthermore, we verify using an independently derived in situ stress tensor that where transverse DITFs are interpreted, close constraints can be placed on the magnitudes of the maximum and minimum horizontal stresses.

1.1. Stresses around a vertical wellbore

Drilling-induced tensile fractures form as a consequence of the stress concentration about the wellbore generated during drilling [10]. As the well is drilled, the wellbore wall must support stresses previously carried by the removed rock. This causes stress concentration about the borehole that depends on the orientations of the wellbore and the far field in situ stress tensor [11–13].

Assuming that the vertical stress is a principal stress, then three principal stresses act about the wall of a vertical well (Fig. 1). These are:

1. the effective radial stress (σ_{rr}) which acts normal to the wellbore;
2. the effective axial stress (σ_{zz}) which acts parallel to the wellbore axis, and;
3. the effective circumferential stress ($\sigma_{\theta\theta}$), which acts orthogonal to σ_{rr} and σ_{zz}.

The near wellbore stresses in impermeable, elastic, homogeneous and isotropic rock are defined by the Kirsch [13] equations. Although the Kirsch equations are simplistic, they are considered to adequately represent the near wellbore stress environment in most regions [1,3,7]. Since petroleum wells are typically drilled overbalanced and mud cake forms at the wellbore wall, the approximation of impermeability is also generally considered valid for reservoir rocks.

The magnitude of the near wellbore stresses depends on the magnitude of the far field effective stresses ($S'_{\mathrm{H\,max}}$, $S'_{\mathrm{h\,min}}$ and S'_{v}), the radius of the wellbore (R), distance from the wellbore (r) and the pore pressure

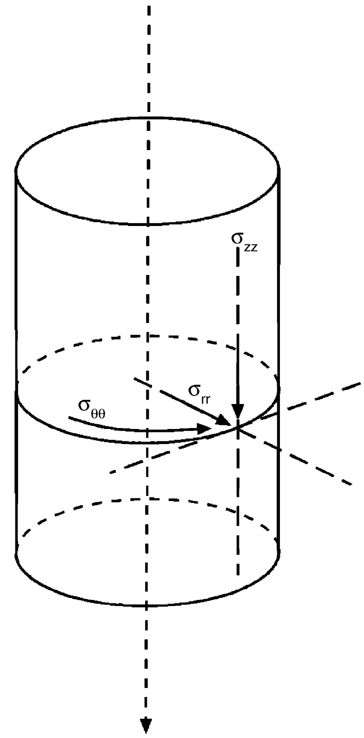

Fig. 1. Vertical wellbore showing orientations of the circumferential ($\sigma_{\theta\theta}$), axial (σ_{zz}) and radial (σ_{rr}) stresses.

(P_{p}). The Kirsch equations are expressed as

$$\sigma_{\theta\theta} = \frac{1}{2}(S'_{\mathrm{H\,max}} + S'_{\mathrm{h\,min}})\left(1 + \frac{R^2}{r^2}\right) - \frac{1}{2}(S'_{\mathrm{H\,max}} + S'_{\mathrm{h\,min}})\left(1 + 3\frac{R^4}{r^4}\right)\cos 2\theta - \frac{\Delta P R^2}{r^2}, \quad (1)$$

$$\sigma_{rr} = \frac{1}{2}(S'_{\mathrm{H\,max}} + S'_{\mathrm{h\,min}})\left(1 - \frac{R^2}{r^2}\right) + \frac{1}{2}(S'_{\mathrm{H\,max}} - S'_{\mathrm{h\,min}})\left(1 - 4\frac{R^2}{r^2} + 3\frac{R^4}{r^4}\right)\cos 2\theta + \frac{\Delta P R^2}{r^2}, \quad (2)$$

$$\tau_{r\theta} = \frac{1}{2}(S'_{\mathrm{H\,max}} + S'_{\mathrm{h\,min}})\left(1 + 2\frac{R^2}{r^2} - 3\frac{R^4}{r^4}\right)\sin 2\theta, \quad (3)$$

$$\sigma_{zz} = S'_{\mathrm{v}} - 2\nu(S'_{\mathrm{H\,max}} - S'_{\mathrm{h\,min}})\cos 2\theta - P_{\mathrm{p}}, \quad (4)$$

where $\tau_{r\theta}$ is the tangential shear stress, ν is Poisson's ratio, ΔP is the difference between mud pressure and pore pressure ($P_{\mathrm{w}}-P_{\mathrm{p}}$), and θ is the angle between the $S_{\mathrm{H\,max}}$ azimuth and north (Fig. 2).

If stresses at the wellbore wall are considered (i.e. where $R = r$), the Kirsch equations may be simplified as