IN-SITU STRESS AND NATURAL FRACTURE NETWORKS IN THE CARNARVON BASIN, NORTH WEST SHELF, AUSTRALIA

The University of Adelaide

Thesis submitted in accordance with the requirements of the University of Adelaide for an Honours Degree in Geology

Gilby Mats Morrison Jepson
November 2014
IN-SITU STRESS AND NATURAL FRACTURE NETWORKS IN THE CARNARVON BASIN, NORTH WEST SHELF, AUSTRALIA

ABSTRACT

A total of 517 naturally occurring fractures are identified on 12 resistivity image logs in Carnarvon Basin on the North West Shelf of Australia. A range of fracture orientations were present. The fractures can be divided in to two sets using image logs. 1) Electrically resistive and conductive fractures orientated NE-SW, 2) electrically resistive and conductive fractures orientated E-W. There are 235 electrically resistive fractures that are considered to be cemented with electrically resistive cements. These electrically resistive fractures dominantly orientated NE-SW. There are 282 conductive fractures that are considered to be uncemented and filled with drilling mud. Thus, these fractures are considered to be open for fluid flow. The conductive fractures are dominantly orientated E-W.

The in-situ stress field is a major control on the ability for fractures to transmit fluid. 123 drilling induced tensile fractures and 175 borehole breakouts present in 12 image logs, determined a mean maximum horizontal stress orientation of $110^\circ$. Leak-off tests and density logs were used to calculate the in-situ stress magnitudes with a vertical stress ($S_v$) of 21.7 MPa/km, a minimum horizontal stress ($S_{hmin}$) of 16.8 MPa/km and a maximum horizontal stress of 23.4 MPa/km ($S_{Hmax}$), this indicates a strike-slip faulting stress regime ($S_{Hmax} > S_v > S_{hmin}$) in the Carnarvon Basin. Using fracture susceptibility plots and Mohr circles constrained by the in-situ stress values, we show that the majority of E-W striking conductive fractures are optimally oriented within the in-situ stress field, demonstrating a high likelihood for fluid transmission. Additionally,
several of these fractures demonstrate significant losses of drilling fluids at corresponding depths. It is likely that the identified conductive fractures are indeed open to fluid flow; demonstrating that these fracture networks provide secondary permeability the Carnarvon Basin subsurface.

KEYWORDS
In-situ Stress, Carnarvon Basin, Natural Fractures, Structural, Geomechanics
### TABLE OF CONTENTS

**IN-SITU STRESS AND NATURAL FRACTURE NETWORKS IN THE CARNARVON BASIN, NORTH WEST SHELF, AUSTRALIA** ........................................ i

Abstract ......................................................................................................................... i

Keywords ........................................................................................................................ ii

List of Figures and Tables ............................................................................................ 2

Introduction .................................................................................................................... 5

Background .................................................................................................................... 8

Geological Setting ......................................................................................................... 8

Interpretation of Geophysical Logs and Well Tests ...................................................... 11

Image Processing .......................................................................................................... 11

In-situ Stress Analysis ................................................................................................. 12

Maximum Horizontal Stress Orientation .................................................................... 15

Pore Pressure Magnitude ............................................................................................. 18

Stress Magnitudes ........................................................................................................ 19

Vertical Stress Magnitude ............................................................................................. 19

Minimum Horizontal Stress Magnitude ....................................................................... 22

Maximum Horizontal Stress Magnitude ....................................................................... 23

Natural Fracture Analysis ............................................................................................. 26

Fracture Formation ......................................................................................................... 27

Fractures Identified in the Carnarvon Basin ................................................................. 27

Fracture Set One (a) ....................................................................................................... 30

Fracture Set One (b) ....................................................................................................... 30

Fracture Set Two (a) ....................................................................................................... 31

Fracture Set Two (b) ....................................................................................................... 31

Lithological Control and Fracture Density .................................................................. 32

Discussion ..................................................................................................................... 34

Maximum Horizontal Stress Orientation .................................................................... 34

Stress Magnitudes ......................................................................................................... 36

Vertical Stress Magnitude ............................................................................................ 36

Minimum Horizontal Stress Magnitude ....................................................................... 37

Maximum Horizontal Stress Magnitude ....................................................................... 38

In-situ Stress regime ..................................................................................................... 39

Structural Permeability ................................................................................................. 40

Fracture Set One .......................................................................................................... 40
Fracture Set Two .................................................................................................................. 41
Fracture Infill .......................................................................................................................... 42
Lithological Control on Fractures .......................................................................................... 44
Fracture Formation and Reactivation .................................................................................... 45
Conclusion .................................................................................................................................. 46
Acknowledgements .................................................................................................................. 48
References .................................................................................................................................. 48
Appendix 1: Methods ................................................................................................................. 52
Data Acquisition ........................................................................................................................ 52
Data Format ............................................................................................................................... 53
Minimum Horizontal Stress ..................................................................................................... 54
Maximum Horizontal Stress .................................................................................................... 56
Image Log Interpretation ........................................................................................................... 57
Reyleigh Test ............................................................................................................................. 65
Stress Magnitudes .................................................................................................................... 66
Vertical Stress .......................................................................................................................... 66
Minimum Horizontal Stress ..................................................................................................... 68
Maximum Horizontal Stress .................................................................................................... 69
Pore Pressure ............................................................................................................................ 69
Effects of Water Depth ............................................................................................................ 70
Natural Fracture Analysis ........................................................................................................ 71
Appendix 2: Well Information Cards ....................................................................................... 74
Appendix 3: Density Log ........................................................................................................... 86

LIST OF FIGURES AND TABLES 4

Figure 1: Location map and stratigraphic log of the Carnarvon Basin, indicating structural elements, proven petroleum fields and sub-basin boundaries (Bernecker et al. 2013). The map displays all wells used in the study, along with the 12 wells that provided image logs. Wells with image logs display the orientation of $S_{H_{\text{max}}}$ provided by both borehole breakouts (BOs) and drilling-induced tensile fractures (DITFs), as well fault regime obtained from stress magnitudes. Fracture magnitude and strike obtained for each of the wells is exhibited in rose diagrams. ............................... 7

Figure 2: C) A cross-section of a borehole illustrating the position of borehole breakouts (BOs) and drilling-induced tensile fractures (DITFs) relative to in-situ stress orientation in a vertical wellbore, with the principal stresses ($\sigma_1$, $\sigma_2$ and $\sigma_3$) are displayed as $S_H$, $S_h$ and $S_v$.  D) A 1:10 scale, static and dynamic, speed corrected Simultaneous Acoustic and Resistivity tool (STAR) image displaying both a BO and DITF (Noblige-
1. A schematic diagram showing the components of obtaining an estimate for $S_v$. As density logs are rarely run from surface, in order to determine the top of density log value, the checkshot velocity is used as a proxy to calculate the initial top of log vertical ($S_v$). B) A pressure versus volume pumped plot, demonstrating Leak-Off Test (LOT) quality, the LOTs are taken from wells; Bleaberry West-1 and Marley-1 (King et al. 2008).

Figure 3: Examples of borehole breakouts (BOs), drilling-induced tensile fractures (DITFs), electrically conductive fractures (CFrac) and electrically resistive fractures (RFrac) displayed as image log features. The wells used are; Acme-1, Bounty-2, Eskdale-1, Charm-1, Grange-1, Noblige-1, Skiddaw-1, Skiddaw-2 and Tidepole-2. Oil-based Micro Imager (OBMI) using an oil-based mud produces an opposite colour scheme to a water-based mud, this is reversed to give a similar, water-based colour scheme.

Figure 4: Depth (m) vs stress (MPa) displaying the stress magnitudes of maximum horizontal stress ($S_{Hmax}$), minimum horizontal stress ($S_{Hmin}$) and vertical stress ($S_v$) calculated from 26 wells located in the Carnarvon Basin in this study.

Figure 5: Rose diagrams displaying the frequency and strike of grey electrically resistive fractures (RFrac) and green conductive fractures (CFrac) from the twelve image logs in the Carnarvon Basin. Dip plots display the depth and dip direction of fractures, electrically resistive fractures are displayed as grey tadpoles, with conductive fractures displayed in green tadpoles. Each well is grouped into fracture sets based on the strike of fractures present, fracture set one (FS1), fracture set two (FS2), fracture set three (FS3) and fracture set four (FS4). Wells with multiple fracture sets present are displayed as: FS1/FS3.

Figure 6: Green roses represents conductive fractures (grey roses are resistive) in the Carnarvon Basin. The three wells all indicate a conductive NE-SW fracture set. The fractures are displayed with dip vs depth plots, with tadpoles indicating dip and dip direction of the conductive fractures.

Figure 7: A) Fracture reactivation plot displaying the potential for reactivation of pre-existing faults and fractures in a strike-slip regime at 1 km depth. B) A Mohr diagram displaying which fractures are most likely to fail under the stress magnitudes experienced at 2.5-3.0 km depth. All plots are done with a 0.6 coefficient of friction.

Table 1: Summary of location, interval, maximum horizontal stress ($S_{Hmax}$) orientations and standard deviation (s.d.) from borehole breakout (BO), and drilling-induced tensile fractures (DITF) over the twelve wells featuring wellbore resistivity image logs in the Carnarvon Basin. Quality ranking according the World Stress Map (WSM) (Heidbach et al., 2010). Four image log types were used: 1) Oil-Based Micro Imager (OMBI); 2) Extended Range Micro Imager (XRMI) and; 3) Simultaneous Acoustic and Resistivity tool (STAR). Qual...
(Figure 2B, Zoback 1992, Heidbach et al. 2009). Water depth was subtracted from depth to when calculating stress magnitudes. Majority of wells in this study displayed a strike-slip fault regime, with two wells presenting a normal faulting regime. Rows highlighted in red indicate wells with drilling-induced tensile fractures present, thus, providing a better constraint for $S_{Hmax}$ using the tensile fracture equation (Equation 5, Brudy and Zoback 1999a). This is opposed to the non-highlighted rows which display just an upper bound for $S_{Hmax}$ (equation 6).

Table 3: Attributes of conductive and resistive fracture sets (Cfrac and Rfrac). Lithological control found for fractures for each well with a lithology report or gamma ray log. Fractures are more likely to be found in lithologies containing sandstone units, however Lady Nora-2 shows that fractures are more likely to be found in mudstones, while Chandon-2 displays a greater number of fractures in limestone units. Not all fractures found are displayed in this table, as no lithological record was acquired for that depth. Number of fractures (n) are separated into; fracture set one (FS1) and fracture set two (FS2). Multiple fracture sets in the same well are denoted by; FS1/FS2.

Table 4: Summary of the contemporary stress field in the Carnarvon Basin. The strike-slip stress regime matches that suggested by previous authors (Neubauer et al. 2007, Bailey et al. in review). In this study, 22 wells displayed a strike-slip fault stress regime, however there were two wells that defined a normal fault stress regime.