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Review of borehole failure mechanism using advanced far field acoustic measurements in complex geological setting, Jaisalmer-Fatehgarh Sub basin.

Abstract

The Jaisalmer-Fatehgarh Sub-basin is located at the North-Western part of India in the state of Rajasthan. This field possesses drilling to completion challenges to tap tight gas depleted reservoir at high stress condition due to complex Geology. There have been many stuck pipe incidents with tight holes, overgauge hole condition and poor data quality resulting NPT and extra cost. This affects quality of data acquisition and uncertainty in formation evaluation to well stimulation design. Mechanism of stuck pipes vary in open hole section with depleted sandstone lying between weak shale/siltstone layers at higher pore pressure. This paper describes how a geomechanical study was used to find the identify possible reasons for observed well complications and way forward on single well basis well design improvement involving mud weight and casing design policy. The study outputs helped to understand the mechanisms responsible for the borehole failures. To overcome the challenges, comprehensive geomechanical studies has been carried out in 2 wells where advanced acoustic measurements are present. The key requirement for any geomechanical analysis is the construction of Mechanical Earth Models (MEMs). The MEM is a numerical representation of the state of in-situ stress and rock mechanical properties for a depth interval. It includes rock elastic and strength properties, in-situ Earth stresses along with pore pressure. Petrophysical, geological and drilling related information are integrated by means of 1-D MEMs. Pore pressure, rock mechanical properties and stress profiles have been estimated in 2 wells to build robust Geomechanical model and estimate stable mud weight window. An advanced Integrated Stress Analysis (ISA) was also carried out from the advanced open hole Sonic data acquired in one of the wells. Presence of critically stressed fractures was also analysed to understand the hole problems.

Introduction

Jaisalmer Basin constitutes the part of western Rajasthan shelf, which represents the westerly dipping eastern flank of the shelf portion of Indus Basin. Western Rajasthan shelf has evolved through vertical uplifts and subsidence during and after the Proterozoic Delhi orogeny. The important Phanerozoic sedimentary basins developed on this shelf are the Bikaner-Nagaur, Jaisalmer and Barmer basins. The present study involves the drilling challenges associated with Lower Cretaceous Pariwar Formation. The Pariwar Formation belongs to Lower Cretaceous age which conformably overlies Baisakhi and Badasar Formation of Upper Jurassic. The beginning of this Formation marks the regression with shallow marine and brackish type depositional environment during Lower Cretaceous. The Pariwar Formation is dominated with Sandstone with interbedded Clay/Claystone. It is well known from the previous studies that Pariwar Formation has fair source potential to yield gas with minor oil. Pariwar Formation faced a regressional facies during their sediment accommodation which is known from their micro-paleontological studies and indicates a marginal and stable shelf depositional environment. One of the major challenges is complex borehole geometry (overgauge and undergauge holes at the layers next to each other) causing several tight hole events and associated nonproductive time (NPT). There is stress rotation laterally and vertically as well due to complex geology. The objective of this paper is to develop a better understanding of the observed complex borehole geometry and associated complications and its mechanism.

Workflow

Petrophysical (including advanced sonic data, **Figure.1**) and drilling data were gathered from 2 wells (1 open hole and 1 cased hole) along with the Geological information. Geomechanical models incorporating formation pressure, vertical and horizontal stresses, elastic and strength properties are constructed. Advanced Geomechanical Integrated Stress Analysis or ISA was carried out to constrain horizontal stresses from dipole sonic radial profiles. Critically Stressed Fracture Analysis was also performed in both wells to capture mechanical stability of natural fractures and their implication on the observed drilling events.

Analysis Overview

In the present study, 2 post-drill MEMs were prepared for 1 open hole (**Figure.2**) and 1 cased hole well (**Figure.4**) sections. History matching of drilling events, calipers, image against MEM based predicted failures using geomechanical workflow was also performed for both the wells.

The overburden stress was obtained by integrating the available density data along with some regional density trends. Pore pressure profile was calibrated with the existing formation pressure test data. Density and sonic data were utilized to calculate the rock elastic properties (Young's Modulus[YM] & Poisson's Ratio [PR]) and rock strength (UCS, Friction Angle & Tensile Strength).

The Poro-elastic horizontal strain model was used for horizontal stress determination in both the wells. This method incorporates PR, YM, overburden stress, Biot's constant, pore pressure and horizontal strains.

$$\sigma_{Hmin} = \frac{\mu}{1-\mu}(\sigma v - \alpha Pp) + \alpha Pp + \frac{E}{1-\mu^2}\epsilon_{Hmax} + \frac{E\mu}{1-\mu^2}\epsilon_{Hmin}$$

$$\sigma_{HMax} = \frac{\mu}{1-\mu}(\sigma v - \alpha Pp) + \alpha Pp + \frac{E}{1-\mu^2}\epsilon_{Hmin} + \frac{E\mu}{1-\mu^2}\epsilon_{Hmax}$$

Where
σ_{Hmin} = minimum horizontal stress
σ_{HMax} = minimum horizontal stress
μ = Poisson's ratio
σv = vertical stress
α = Biot's constant
P_p = pore pressure
E = Elastic modulus
ϵ_{Hmax} = maximum horizontal strain
ϵ_{Hmin} = minimum horizontal strain

An advanced approach, Integrated Stress Analysis or ISA, was also used to constrain the magnitude of the maximum horizontal stress in the open hole logged section (Pistre et.al). ISA allows us to calculate the magnitude of maximum horizontal stress from the shear radial profile and 3 far-field shear moduli (fast, slow and Stoneley shear). This method is based on perturbation theory of stress-dependent elastic model where the changes of the 3 far-field shear moduli from a hydrostatic reference state can be attributed to the changes in the principal stresses. The values of the maximum horizontal stress from both the methods compared quite well with each other.

Critically stressed fracture analysis was performed in both the wells to examine the presence of natural fractures which are critically stressed (mechanically unstable or on the verge of slipping). This analysis is based on a simple analytical approach based on Mohr-Coulomb shear failure criterion. It calculates the normal and shear stress components on a fracture plane depending on its orientation (i.e. dip and azimuth) and analyzes whether it is stable or on the verge of shear sliding in the present-day stress state. In addition, advanced hole shape analysis was also performed from the 4-arm caliper logs and image data to examine the nature breakout rotation.

Findings & Conclusions

Based on the comprehensive analysis, key summary points are below:

- Stress regime can be seen varying from Strike – Slip to Thrust Fault.
- Significant wellbore tortuosity can be depicted based on caliper and fast shear azimuth variation.
- Wellbore failure is complex – mixture of shear failure, fault / bedding plane slippage mechanisms and undergauge hole in stiff depleted sandstone
- “Breakouts” seen by the calipers are observed to be asymmetric and “rotating” (**Figure.2**)
- Hole is observed to be under-gauge in the In-Situ maximum stress direction only.
- There is no indication of clay swelling related signature on the shear velocity radial profile logs and available XRD data.
- Presence of high angle structural features (natural fractures, Echelon and vertical DIF [**Figure.3**]) suggest ratio of SigH to Sigh ~1.3-1.8 as predicted by MEM and advanced shear radial profile (**Figure 2)**.
- Few BHA helps up and stuck are reported in layers with varying stiffness and UCS, possible ledges.
- Current mud weight plan is not sufficient to minimize drilling events. Mud weight must be increased up to 11.5ppg proactively with additives to minimize filter cake in depleted sandstone.
- Considering long open section of 1500m-1600m and BHA trips, additional casing shoe can be set in at top of target formation with (~500m-600m) thickness. This will isolate problematic layers with overburden limestone and shale layers.

References

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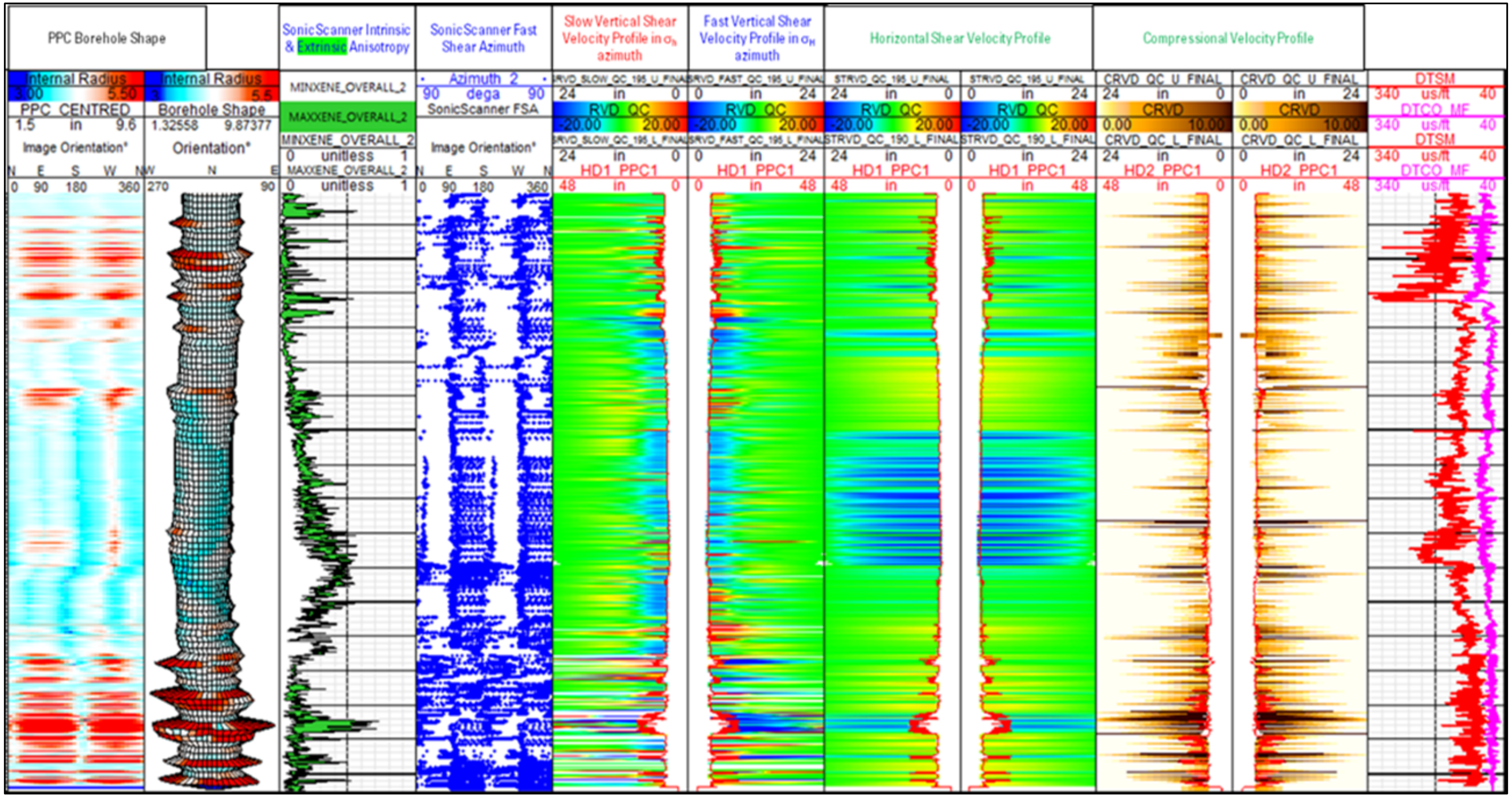


Figure 1: Advanced Sonic Radial Profile of the Open Hole Well (Red showing weak zones, which is matching well with hole shape)

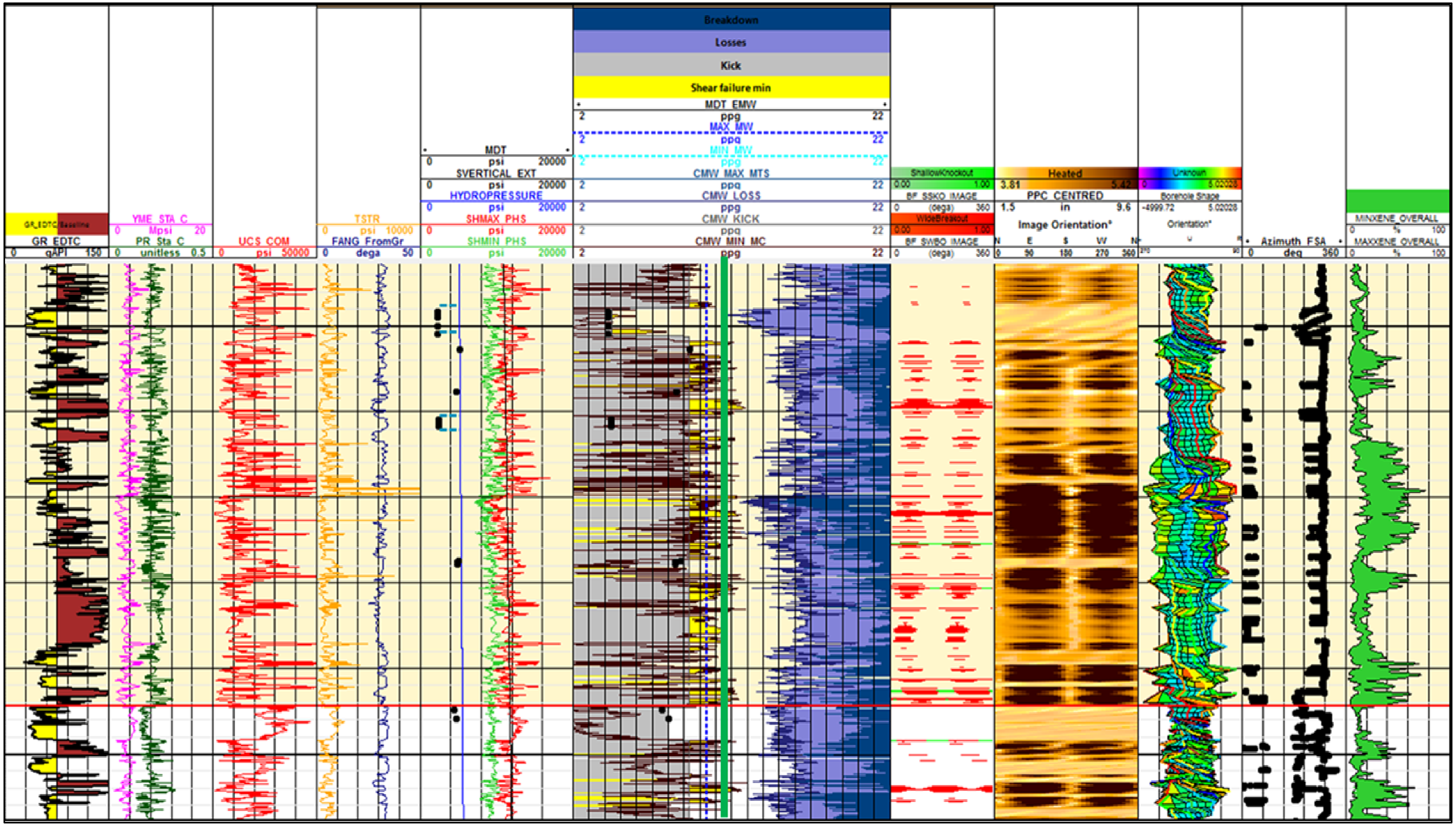
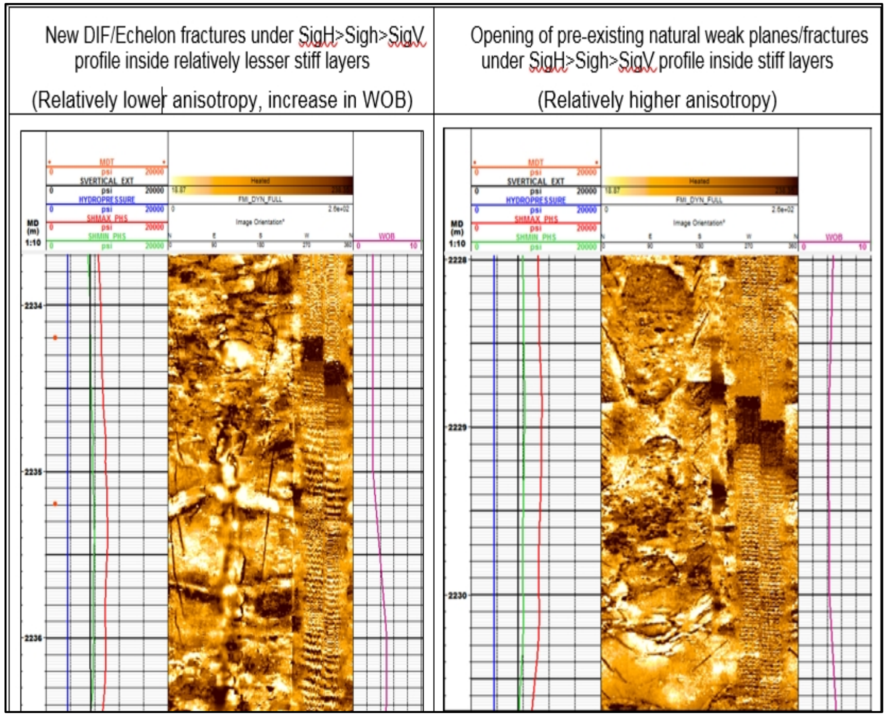


Figure 2: MEM Construction using calibrated stress profile to history match borehole failure


New DIF/Echelon fractures under SigH>Sigh>SigV profile inside relatively lesser stiff layers
(Relatively lower anisotropy, increase in WOB)
Opening of pre-existing natural weak planes/fractures under SigH>Sigh>SigV profile inside stiff layers
(Relatively higher anisotropy)
MDT
psi 20000
SVERTICAL_EXT
HYDROPRESSURE
SHMAX_PHS
SHMIN_PHS
FMI_DYN_FULL
Healed
Image Orientation°
WOB
MD (m) 1:10
2234
2235
2236
2228
2229
2230

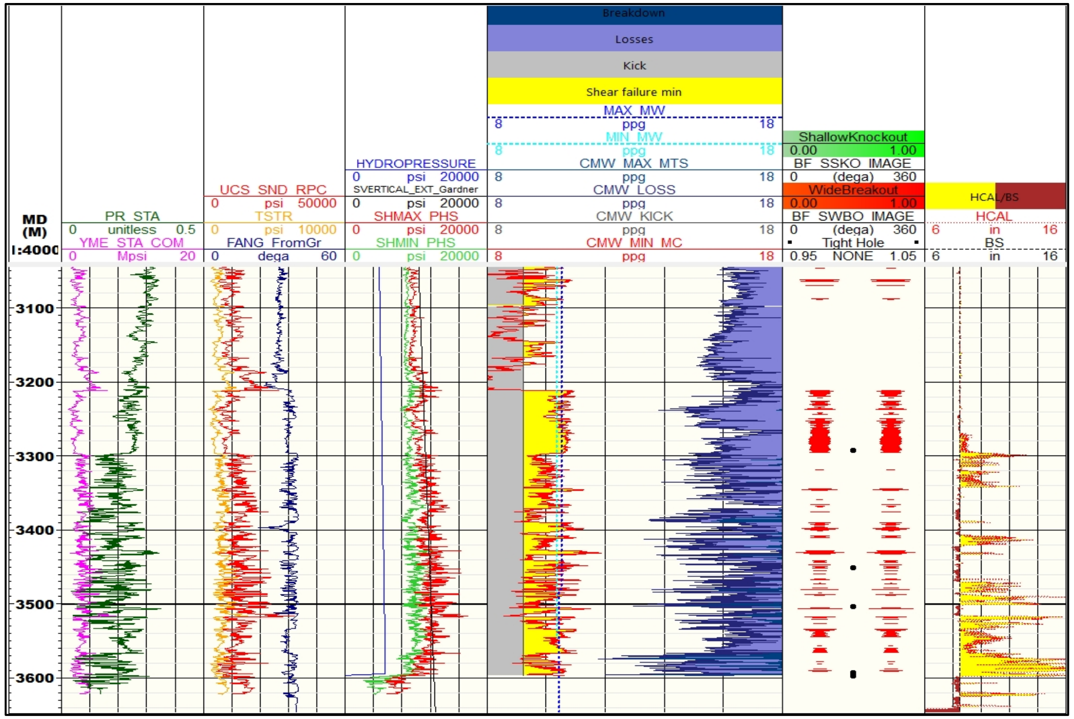

MD (M) 1:4000
PR_STA
0 unitless 0.5
YME_STA_COM
0 Mpsi 20
UCS_SND_RPC
0 psi 50000
TSTR
0 psi 10000
FANG_FromGr
0 dega 60
HYDROPRESSURE
0 psi 20000
SVERTICAL_EXT_Gardner
0 psi 20000
SHMAX_PHS
0 psi 20000
SHMIN_PHS
0 psi 20000
Breakdown
Losses
Kick
Shear failure min
MAX_MW
8 ppg 18
MIN_MW
8 ppg 18
CMW_MAX_MTS
8 ppg 18
CMW_LOSS
8 ppg 18
CMW_KICK
8 ppg 18
CMW_MIN_MC
8 ppg 18
ShallowKnockout
0.00 1.00
BF_SSKO_IMAGE
0 (dega) 360
WideBreakout
0.00 1.00
BF_SWBO_IMAGE
0 (dega) 360
Tight Hole
0.95 NONE 1.05
HCAL/BS
HCAL
6 in 16
BS
6 in 16
3100
3200
3300
3400
3500
3600

Figure 3: Natural Fractures and DIFs seen in the Open Hole Images

Figure 4: Calibrated MEM of the Cased hole well (modelled failures matching with well events and Caliper)