3D Geomechanics Characterization in V Field

R Marbun$^{1,a}$ and A Haris$^{2,b}$

$^1$Reservoir Geophysics Graduate Program, Physics Dept, Universitas Indonesia
Jl. Salemba Raya no. 4, Jakarta 10430, Indonesia

$^2$Physics Department, FMIPA, Universitas Indonesia
Kampus UI Depok, Depok 16424, Indonesia

Email: $^a$ricki.daniel.marbun@gmail.com, $^b$aharis@sci.ui.ac.id

Abstract. Upstream oil & gas operators faced many challenges in drilling activities during a field development phase where the reservoir pressure depletion might disturb the stresses equilibrium in the formation and triggered stress redistribution in the reservoir and its surrounding rocks. These changes could lead into more problematic drilling experiences such as the narrowing of safe drilling mud weight windows due to the decreasing of fracture and increasing of breakout gradients in a well scale and even in a field scale, as well as potential operation losses due to related wellbore instability issues. Geomechanics analysis conducted to identify the stress redistribution and predict the field wellbore instabilities behaviour that honour the geological features in the area. The 1D Geomechanics model is created for offset wells which consist of rock strength and elastic properties, pore pressure and stresses profiles. Seismic inversion volume is used to populate the properties in the 3D static model and field Geomechanics simulation conducted to obtain the field stresses profile. V field data is used as the data available in this field is complete to support this study (wire-line logs, petrophysical interpretations, VSP, core analysis, production log, drilling reports, and the seismic velocity cube). The results of the integrated reservoir Geomechanics characterization with seismic inversion managed to predict the wellbore instabilities model in the offset wells.

1. Introduction

Upstream oil & gas operators faced many challenges in drilling activities during the development phase of a field. In this phase, the reservoir pressure depletion might disturb the stresses equilibrium in the formation and triggered stress redistribution in the reservoir and its surrounding rocks. This change could lead into more problematic drilling experiences such as the narrowing of safe drilling mud weight windows due to the decreasing of fracture and increasing of breakout gradients in a well scale and even in a field scale, as well as potential operation losses due to related wellbore instability issues.

Reservoir Geomechanics analysis is needed to identify the redistribution of current, pressure, including its magnitude and direction, which is important for modelling borehole stability to simulations of reservoir compaction and surface landslides. In 3-D modelling, to obtain lateral lithological variations, seismic interval velocity data can be used as guidelines and trends in the distribution of good data to field models. Seismic velocity data itself can be obtained from various methods. One example is Amplitude versus Offset (AVO) analysis [Ref. 5: Aki & Richards, 1980] which has been widely used in the oil and gas industry to help detect hydrocarbons, identify lithology, and analyse fluid parameters. From this AVO analysis, seismic amplitude inversion can be performed to extract information about the geological conditions that produce the existing seismic response. Various kinds of seismic inversion methods currently exist, one of the examples is Acoustic Impedance (AI) inversion. Seismic inversion methods...
volume will be used as the guideline in distributing geomechanical properties in surrounding formation around the reservoir zone. Meanwhile, reservoir porosity model will be used as the guideline in distributing the geomechanical properties in reservoir.

Data from V Field will be used in this research. This field (Figure 1) is located 200 kilometres west of the town of Stavanger in the far south of the Norwegian area. The availability of data in this field is considered sufficient, such as wire-line logs, petrophysical interpretation, vertical seismic profiling (VSP), rock core analysis, production logs, drilling reports, static and dynamic geological models, and seismic velocity cubes. The hydrocarbons produced from the Hugin formation have good reservoir characteristics. The field was first discovered in 2008 and has produced 2 times the volume of hydrocarbons initially estimated. Seismic acquisitions have been carried out before and after the production period. The field is located west of Stavanger and was decommissioned in 2016 after 8.5 years of production.

Figure 1. Study Location.

2. Regional Geology
The regional geology of the field is located in the North Sea basin and is structurally part of the South Viking Graben. This sub-chapter will discuss the geology of the research area in the form of physiography, stratigraphy, tectonics and geological structures.

2.1. Physiography
The South Viking Graben is an asymmetrical half-Graben located in the northern area of the triangular rift system in the North Sea [Ref. 1: Jackson et al, 2008]. This Graben has some hydrocarbon accumulation with an estimated recoverable reserve of 340.7 x 106 Sm3 oil equivalent. This half-Graben develops on a north-south axis with the western boundary in the form of GBFZ (Graben Boundary Fault Zone) which is a normal fault with a north-south strike direction. In the east, this Graben is bounded by an elevated area, namely Utsira High.

2.2. Stratigraphy
Sediment deposits in this area start from the oldest Middle Jurassic age of the youngest Quaternary age. The rocks deposited in this area are mostly sedimentary rocks in the form of sandstone, claystone and carbonate. In addition to sedimentary rocks, there are also deposits of classic volcanic rocks in the Balder formation of the Early Eocene age. The depositional environment of rocks in this area is quite varied, ranging from eustatic areas, shallow seas such as deltas and carbonate deposits as well as deep-sea depositional environments (Gradstein, 2010). The reservoir rock candidates in the Volve field are the Hugin formation and the Ty formation, both of which have good porosity [Ref. 2 & 3: Husmo et al. 2003, Isaksen & Tonstad. 1989]. The source rock in this field is the Draupne formation which was
deposited in the late Jurassic age. This formation is dominated by organic material in the form of marine algae with type II kerogen. This formation has reached a level of maturity sufficient to produce gas and oil. The cap rock in this field is generally in the form of claystone and shale which was deposited above the reservoir formation and has a fairly low permeability.

2.3. Regional Tectonic and Geology, Structure
Valve Field located in the South Viking Graben area is at the junction between the 3 major elemental structures in the North Sea. These 3 structural elements are the Jurassic fault block at the Utsira High to the west, the Jaren High to the south and the Graben boundary in the form of a normal fault along the Fladen Ground Spur boundary to the west. In the Paleozoic era the stress regime in this area was compressional with right lateral movement. Extensive rifting occurred after the Early Permian to Late Jurassic, with the most intensive rifting occurring in the Late Jurassic. During this rifting the reservoir rock in this field was deposited and at the same time extensional faults were formed in the form of normal faults. Valve Field has a dome-shaped structure formed by the collapse of the adjacent salt deposit ridge in the Middle Jurassic.

3. Method
The outline of the research methodology is shown in Figure 2. The research is divided into two (2) work sections: well scale and field scale. For the well scale, the software that will be used include Microsoft Excel spreadsheet and Techlog™. As for the field scale, the software that will be used is Petrel™ and Visage Geomechanics Simulator™.

Figure 2. Workflow of the study.

3.1. 1D Geomechanics Model Construction
1D Geomechanics modeling started by understanding the available data and reviewing the offset wells data, for this study are wells 19-A and 19-BT2. Next, mechanical stratigraphy of each wells are built to differentiate the clastic and carbonate formations that will help in the consideration during assigning calculation of geomechanical properties. Elastic properties, Young’s modulus and Poisson ratio, are generated using available compressional, shear Sonics; and density log data. Then, rock strength properties, such as: Unconfined Compressive Strength (UCS), Tensile Strength, and Friction Angle are generated using available compressional sonic and gamma ray logs data. Pore pressure modeled using an Eaton method [Ref. 7: Ben A. Eaton, 1975], where the models were calibrated using available reservoir formation testing (RFT) data. Next, stresses profiles are generated for the offset wells using Poroelastic method. Closure pressure data is available in well 19-A and is used to calibrate the minimum
horizontal stress magnitude. Moreover, available borehole image data is used to understand the horizontal stresses orientation.

![Geomechanics properties in well 19-A and 19-BT2.](image)

**Figure 3.** Geomechanics properties in well 19-A and 19-BT2.

### 3.2. Acoustic Impedance Seismic Inversion

In order to honor the geological variation and features in the area, available seismic data is used to do the Acoustic Impedance inversion. Sonic from wells were calibrated with available VSP Checkshots. Next, wavelets are extracted to perform the seismic to well tie. Extended white method was used to extract the wavelet from the seismic. Low frequency model from available seismic data was created with a high cut filter at 6 Hz and slope of 30 dB/octave. The inversion result has relative misfit of -7.71 dB (16.9% energy), with the relative number of reflectors 25.3%. Figure 4 below shows the result of Acoustic Impedance inversion.
3.3. 3D Geomechanical Modelling

3D Geomechanics modeling started by conducting the model embodiment over the reservoir part. This embodiment consist of overburden, sideburden and underburden zones. The purpose of each zone is to simulate the actual condition of stress propagation from the major tectonic stress event (i.e. Major faults) and tectonic plate movement in below. For pore pressure model, pore pressure prediction conducted by applying Eaton trendline, that obtained during geomechanical analysis in offset well, versus true vertical depth subsea (TVDSS) profile. Figure 5 shows the embedded geomechanical model of the study. Geomechanical properties of offset wells, then populated in the embedded grid of the model. In Reservoir zone, properties are populated based on porosity model. For Overburden zone, properties are populated based on seismic inversion volume. For Sideburden and Underburden zones, properties are populated based on the moving average method. Figure 6 shows the populated properties in the reservoir and overburden zones.

![Figure 4. Acoustic Impedance Inversion Result. The QC section is plotted along the wellbore trajectory. The inversion managed to show the impedance contrast of each formations, with range of 3,000 (purple) to 13,000 kPa.s/m (red).](image)

![Figure 5. Geomechanical model embedment.](image)
Figure 6. Populated geomechanics properties in Overburden and Reservoir zones.

4. Results and Discussion
4.1. Pre-production Field Stresses Results
Pre-production stress simulation conducted by using the populated and generated Geomechanics parameters above [Ref. 9: Blanton & Olson, 1999]. Equilibrium stresses calculated with the finite element Geomechanics simulator, Visage™. Geomechanical simulation resulting the stresses profiles across the field as shown in Figure 7. 1D Geomechanics properties, then are compared with 3D Geomechanics simulation results (pore pressure, minimum horizontal stress, maximum horizontal stress, and vertical stress) to ensure the results are inconsistent trend in the well scale data as shown in Figure 8.
4.2. Wellbore Stability Prediction for Target, Wells

Wellbore stability (WBS) model in the target wells can be calculated and predicted using the resulted stresses profile across the field. The WBS resulted the recommended mud weight window to be used by the drilling team in the drilling operations as shown in Figure 9. The results show a very narrow window in both target wells.

**Figure 7.** Pre-production stresses simulator results.

**Figure 8.** Comparison of offset wells stresses profile and field stresses profile results.
Figure 9. Drilling mud weight window from wellbore stability prediction in F-4 and F-5.

This mud weight window consists of Kick mud weight (MW) range, Breakout MW, Losses MW, and Breakdown MW. Kick MW represents the pore pressure profile along the well trajectory. Breakout MW represents the potential welfare failure due to formation breakout if the MW is in this zone. Losses MW represents the potential reactivation of existing natural fractures in the borehole that can lead to mud weight loss into the formation. Breakdown MW represent the potential of new drilling induced fractures generation due to the high mud weight being used during drilling and is in this zone.

Based on the results of mud weight windows for wells F-4 and F-5, Table 1 and 2 shows the recommended casing points and mud weight.

Table 1. Well F-4 casing points and mud weight recommendation.

| Casing Section (inch) | Depth (MMD) | Recommended MW (g/cc) |
|-----------------------|-------------|------------------------|
| 13-3/8                | 1,650       | 1.50                   |
| 9-5/8                 | 2,525       | 1.65                   |
| 7                     | 3,000       | 1.40                   |
Table 2. Well F-5 casing points and mud weight recommendation.

| Casing Section (inch) | Depth (MMD) | Recommended MW (g/cc) |
|-----------------------|-------------|-----------------------|
| 13-3/8                | 2,025       | 1.50                  |
| 9-5/8                 | 2,700       | 1.65                  |
| 7                     | 3,395       | 1.20                  |

5. Conclusions
Based on the results of 3D Geomechanical characterization in V Field, following points are concluded:

- Seismic inversion method managed to honour the geological variation and features on the geomechanical propagation.
- Geomechanical simulation resulted the stress profile across the field and this was used to generate the wellbore stability analysis of V Field.
- The wellbore stability analysis gives the recommended casing points and mud weight for the target wells that can help the drilling operation pre-planning hence drilling hazards can be better prevented and mitigated.

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