Stringers in Zechstein salt as a drilling risk

Case study Ruby exploration well
Introduction

- Predrill Ruby well assumptions

- Post well analysis of N05-01-S1, N05-01-S2 and N05-01-S3 wells
  - N05-01-S2 experienced a kick in the Z3 Carbonate

- Semi-regional pore pressure model to predict kick magnitude
  - Compaction disequilibrium
  - Additional uplift

- Movable salt to predict overpressure in carbonate stringers

- Seismic modeling to understand pore pressure
  - Can seismic bright spots be used as a predicting tool?

- Approach for future wells
  - Subsurface geometry
  - Drilling technique
Predrill Ruby well assumptions

- Drill through the axis of a syncline
  - Avoid hitting a floater, rather a sinker, to avoid pressures being brought to shallower level
  - Avoid hitting steep dips at Z3 level
  - Smallest change of potential gas column

- In nearby wells (N04-01, N04-02, L08-P01A the Z3 Carbonate is non existent or very thin with poorly developed porosity.
Syncline (Trough) in Z3 Carbonate Mb

Original plans for N05-01 and N05-01-sidetrack were based on the concept of drilling through a trough or syncline in the Z3 Carbonate Mb. In the case of N05-01 this turned out successful: no Z3 Carbonate Mb or floater was seen in the well.
**Sidetrack Plans**

Original plan: Side track out of 9 5/8” casing below Z3 Carbonate Member

Revised plan: Side track out of 9 5/8” casing above top Zechstein Group
N05-01-S2 Zechstein kick summary

- After drilling through Z3 Main Anhydrite Member, kick in suspected Z3 Carbonate Member

- Flow rate increasing to 1500lpm while shutting in well

- Well did not become statically stable
  - Only dynamically with 1.84sg mud weight and 450gpm circulation

- BHP pressure rises with mud weight increases, chasing a moving target
  - Initial SIDPP: 64 bar with 1.51sg mud, 481 bar at 2813mTVD
  - First well kill: 13 bar with 1.84sg mud, 521 bar at 2813mTVD
  - Second well kill: 5 bar with 1.91sg mud, 532 bar at 2813mTVD

- Tripping in and out not possible

- Decided to cement in BHA
Five step plan to recover from kick

1. SET CAT PLUG INSIDE BHA
2. LOCATE FREE POINT SEVERE PIPE
3. SET CAT PLUG ON TOP OF BHA
4. Plug back, SET KICK/OFF Plug
5. Repeat until annulus plugged

OK: Side track around floater
NOT OK: P & A.
Syncline in Z3 Carbonate Mb, Floater Horizon

However N05-01-S2 unexpectedly found a floater
Section along Yellow Line on previous slide
N05-01-S3 is planned in very close proximity to the N05-01-S1, and parallel to the Syncline

No Z3 Carbonate Mb

Kick
For N05-01-S3 we planned to return to the original location of N05-01-S1 to provide (safe) passage through the Z3 Carbonate Mb in the Trough.
Post well analysis

- N05-01-S1 experienced no kick, no Z3Carbonate, instead ~150m Z3 Main Anhydrite was encountered

- N05-01-S2 experienced a kick of ~1.93 SG EMW after drilling ~60m through Z3 Main Anhydrite

- N05-01-S3 experienced no kick, similar geology with N05-01-S1
  - 25m lateral from original hole
Ikon Science estimates a potential overpressure in Zechstein stingers based on the compaction trend of shales and the subsequent uplift of the stringer.
Movable salt creating overpressure in carbonate stringers

- Isolated carbonate stringers are being pressurized by movable salts being squeezed into the pores.
  - Ultimately pressure of carbonate stringers cannot exceed SG of the movable salt
Seismic modeling to understand pore pressure

- Can seismic bright spots be used as a predicting tool for overpressured carbonate stringers?
Seismic modeling to understand pore pressure

- Can seismic bright spots be used as a predicting tool for overpressured carbonate stringers?

**NO**

- Reflection of Z3 Main Anhydrite in N04-02 (no Z3 Carbonate) shows higher amplitude than N05-01-S2 (kick)
  - Seismic reflector amplitude brightens at tuning thickness of Z3 Main Anhydrite (20 – 70m)
  - 12% difference in base Z3 Main Anhydrite reflection between N05-01-S2 and N04-02 due to tuning
- Adding Z3 Carbonate to predicting model has the effect of dimming reflection at base Z3 main Anhydrite

- Simulating overpressured pores the acoustic velocity might increase (water compressibility ↑, elastic properties minerals ↓, gas saturation equilibrium ↑ ↓, diagenesis ↓)
  - Increasing in Vp/Vs (VES) from 40 – 140 bars gives a 10% increase in amplitude at base Z3 Main Anhydrite

- Tuning effect is probable cause for high amplitudes at Z3 Main Anhydrite (main well, sidetrack and N04-02)
- Slight increase of reflectivity below Z3 Main Anhydrite might represent overpressure (avoid).
Seismic comparison with N04-02

The reflections at the top and base main anhydrite are generally bright.
Zechstein well ties

The amplitude of the top and base main anhydrite reflection is much higher in N04-02
Scenario I - Wedge based on Interpolated well data

Thinning of the main anhydrite in N05-01 S1 results in a 35% increase in amplitude due to tuning
Amplitude Response of blocky model using Ricker and Extracted Wavelets wavelet

12% difference in base main anhydrite reflection between N05-01 and N04-02 due to tuning
Wedge Models Comparing effects of Carbonate member

- Adding in the Platten Dolomite has the effect of dimming the reflection at the base of the main anhydrite
- Tuning effects are very similar in both models
Ways that Pore Pressure Impacts Velocities

- Increasing pore pressure softens the elastic mineral frame by opening cracks and flaws, tending to lower velocities.

- Increasing pore pressure tends to make the pore fluid or gas less compressible, tending to increase velocities.

- Changing pore pressure can change the saturation as gas goes in and out of solution. Velocities can be sensitive to saturation.

- High pore pressure persisting over long periods of time can inhibit diagenesis and preserve porosity, tending to keep velocities low.
Slab Model - Z3 Grey salt member overlying Z2 Strassfurt Formation

Six VES locations were sampled and the resulting Vp, Vs values were used to create the blocky model below.
Slab Model - Z3 Grey salt member overlying Z2 Stassfurt Formation

⭐ Typical effective stress at N05-01 well - 140 bars
⭐ Calculated effective stress of kick 41.2 bars

A change in VES from 40 - 140 Bars gives a circa 10% increase in amplitude on the Z3 anhydrite /Grey clay interface.
N07-04 Planning
N07-04 (Tanzaniet)
N07-04 Zechstein strategy development

- 13 3/8” shoe in top Zechstein: 2136mMD (2100mTVD)

- Z3 Main Anhydrite Member: 2620mMD (2565mTVD)

- Z3 Carbonate Member (potential kick zone), if present: 2658mMD (2602mTVD)

- Z3 Grey Salt Clay Member: 2668mMD (2612mTVD)

- Z3 Carbonate Member is a potential kick zone like in N05-01X, if present at all, and has an expected thickness of 10mTVD. How to get through this zone?

- Drill with high (1.9-2sg) mud weight: well will not be statically stable
  - N05-01X showed that the well will not become stable with a higher mud weight

- Drill with a flowing kick zone: flow too high, too many unknowns, too risky
  - N05-01X kick zone flowed with 1500lpm
  - Overlying Zechstein salt needs 1.5sg mud weight, what happens with unknown weight of brine in hole?

- Any option involving tripping in or out with drill string or casing not possible

- Stopping circulation for connections will accommodate the mud/brine flip and contaminates mud system

- Drilling with casing or liner and cementing it in, eliminates the need to trip

- Drilling with MPD and a continuous flow system allows to drill with 1.50sg mud and keeps the well constantly dynamically stable

Drill 12 1/4" hole conventionally into Z3 Main Anhydrite. POOH.

RIH with 650m 9 5/8" liner. Drill with liner through Z3 Carbonate Member (potential kick zone).

1) No kick
POOH liner and continue drilling 12 1/4" hole conventionally

2) Kick encountered
Cement liner in hole, tie back 9 5/8" to well head. Continue down scaled.

**mMD mTVD**
Lower Buntsandstein

2115 2080 Z4 Aller Fm

2209 2170 Z3 Leine Fm

2297 2255 Z3 Salt Mb

2620 2565 Z3 Main Anhydrite Mb

2658 2602 Z3 Carbonate Mb (potential kick zone)

2668 2612 Z3 Grey Salt Clay Mb

2673 2616 Z2 Stassfurt Fm

2694 2636 Z2 Roof Anhydrite Mb

2720 2661 Z2 Salt Mb