ORANJE-NASSAU ENERGIE

Stringers in Zechstein salt as a drilling risk

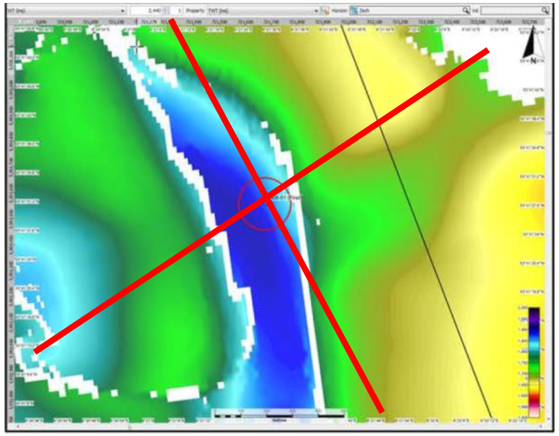
Case study Ruby exploration well

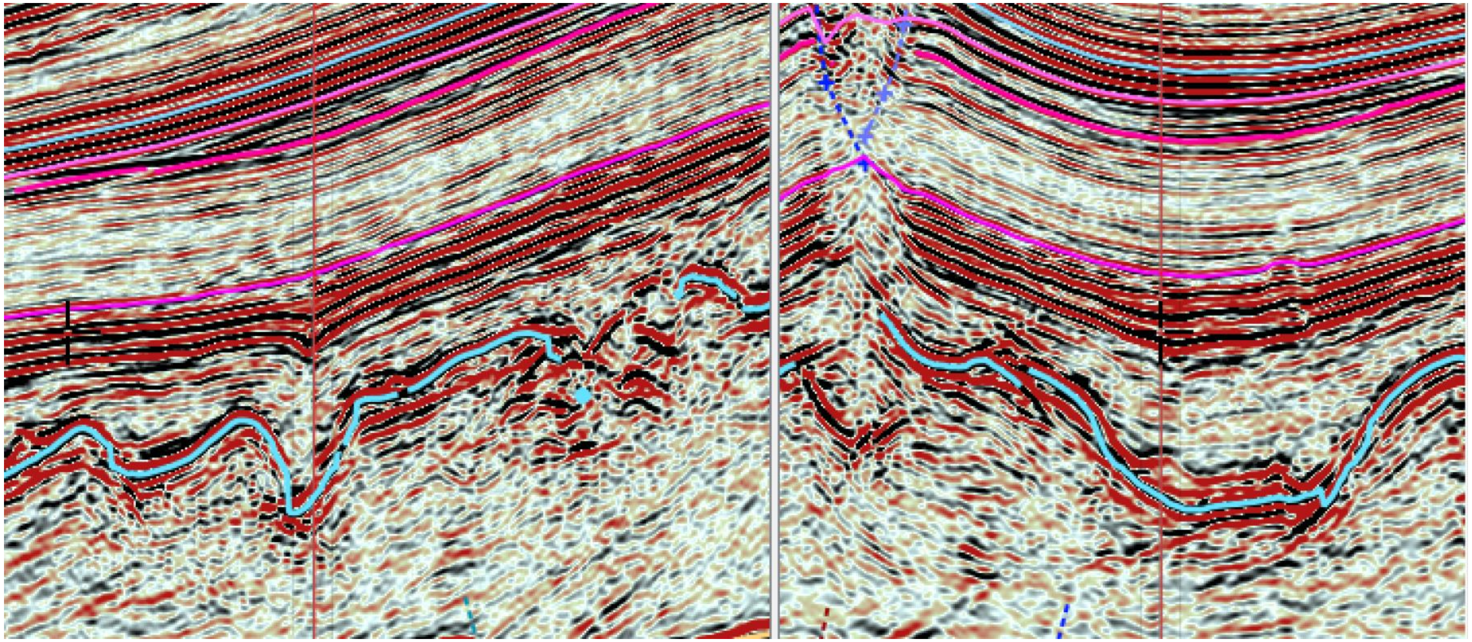
Introduction

- 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 dissequilibrium
  - 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

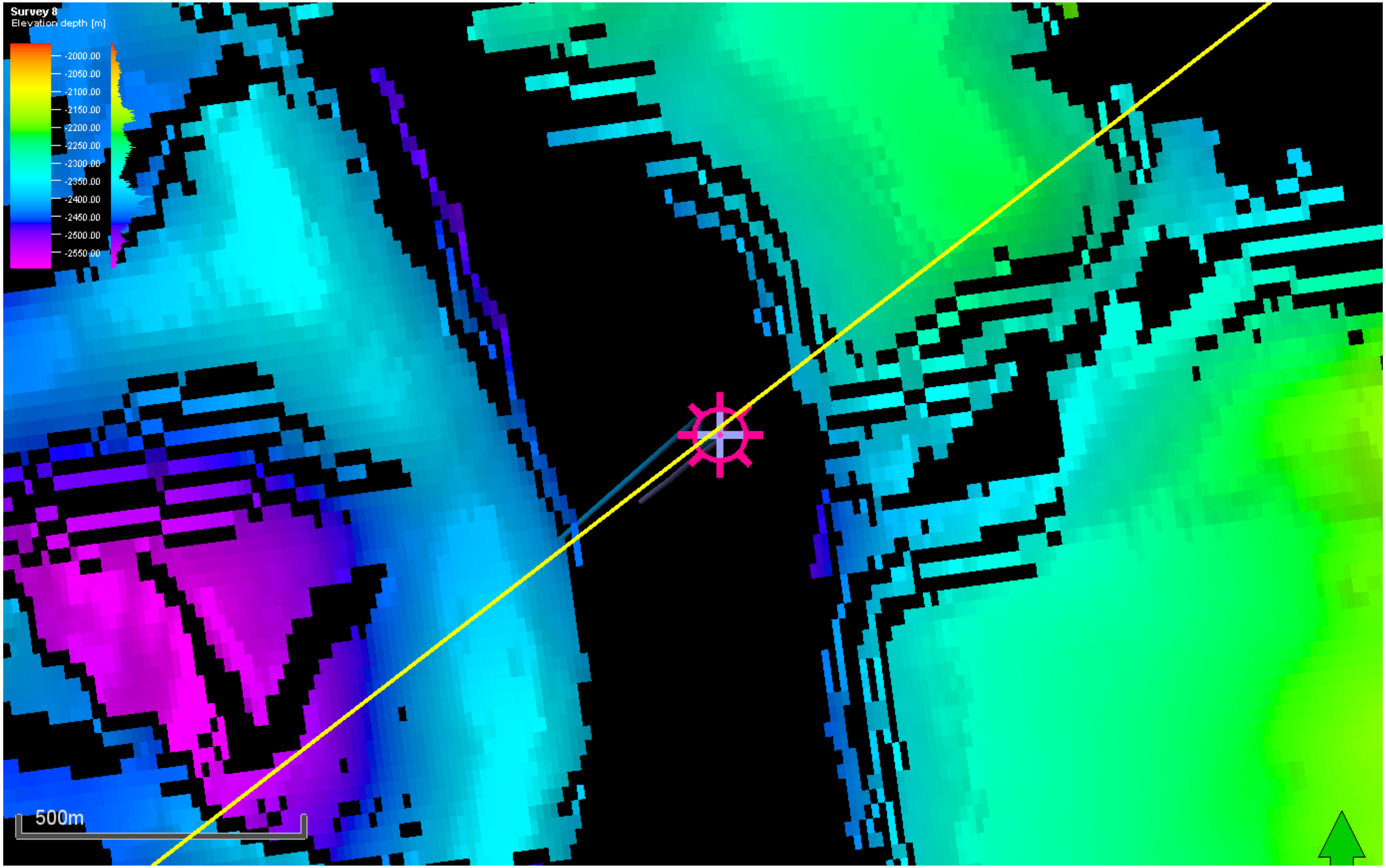
- Drill through the axis of a syncline
  - Avoid hitting a floater, rather a sinker, to avoid pressures being brought to shallower level
  - Avoid hitting steep dips at Z3 level
  - Smallest change of potential gas column
- In nearby wells (N04-01, N04-02, L08-P01A the Z3 Carbonate is non existent or very thin with poorly developed porosity.





ORANJE-NASSAU ENERGIE

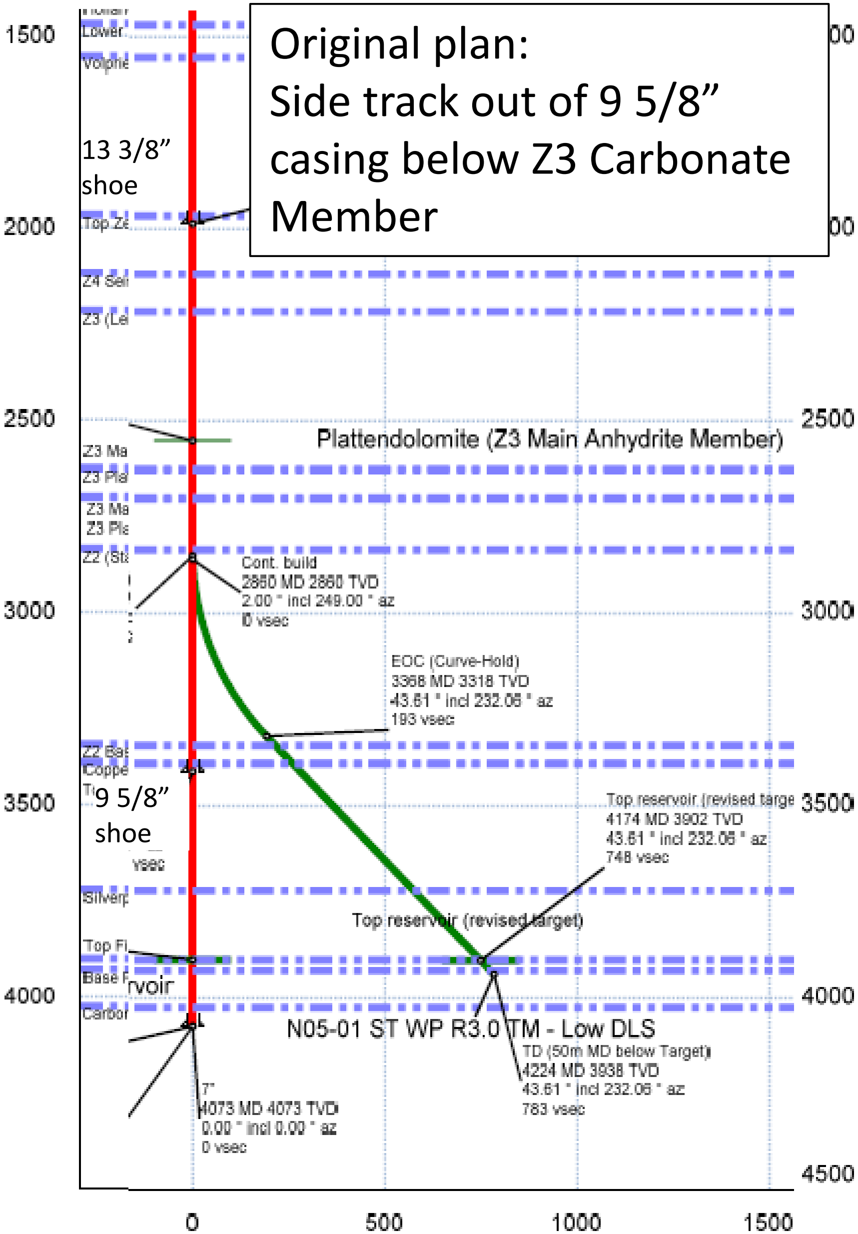
Syncline (Trough) in Z3 Carbonate Mb

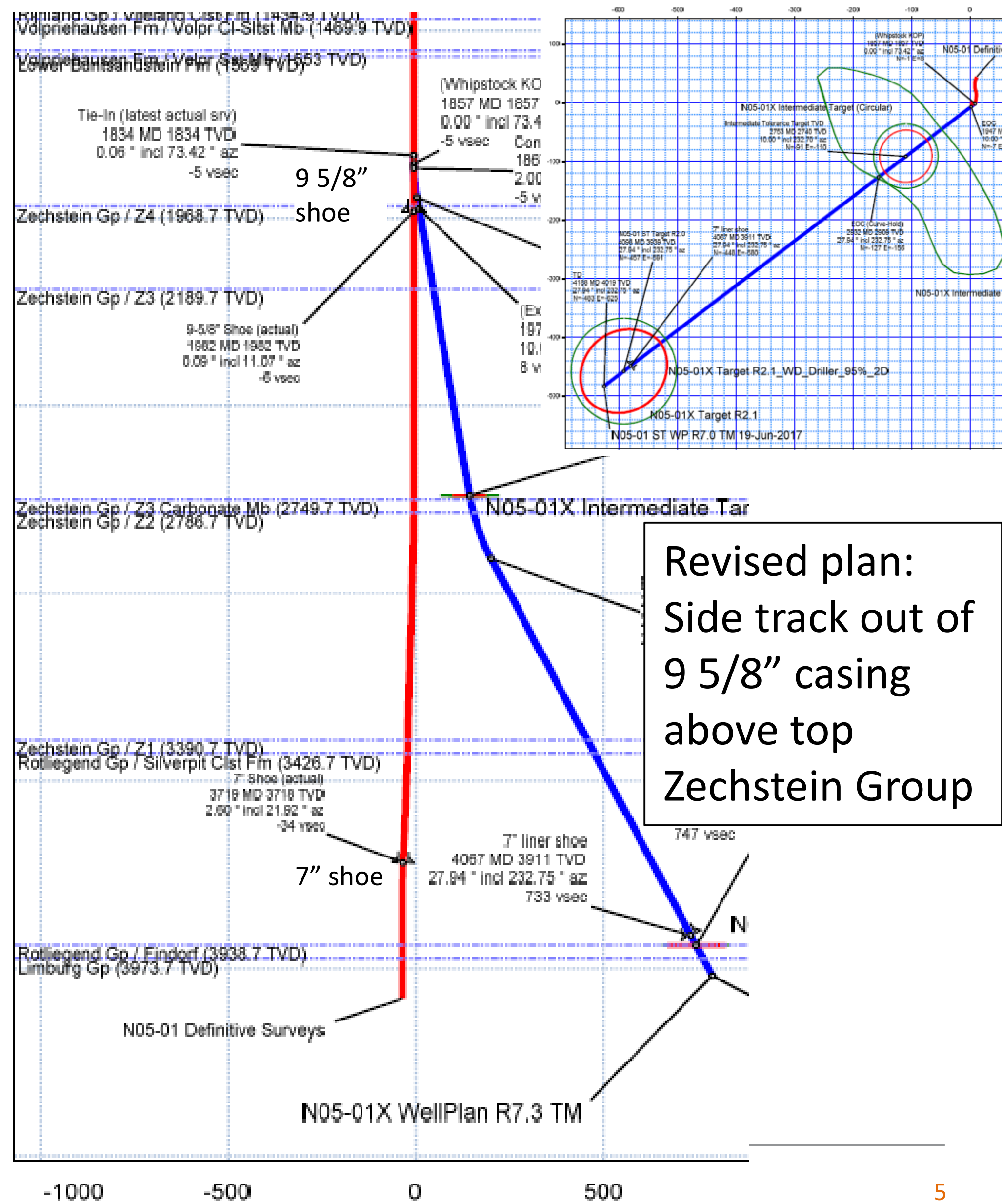


Original plans for N05-01 and N05-01-sidetrack were based on the concept of drilling though a trough or syncline in the Z3 Carbonate Mb. In the case of N05-01 this turned out succesful: no Z3 Carbonate Mb or floater was seen in the well

ORANJE–NASSAU ENERGIE

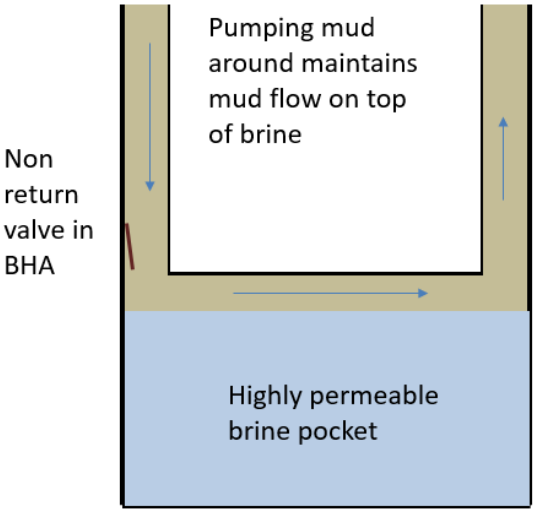
Sidetrack Plans

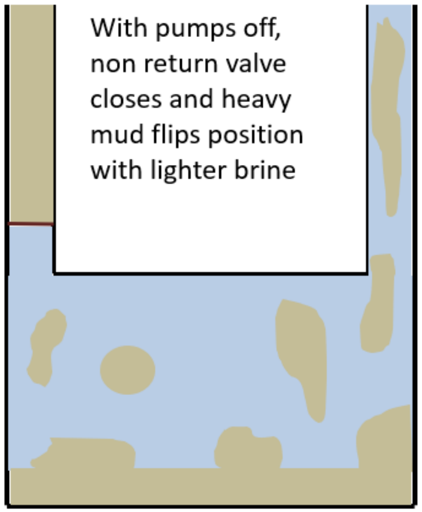




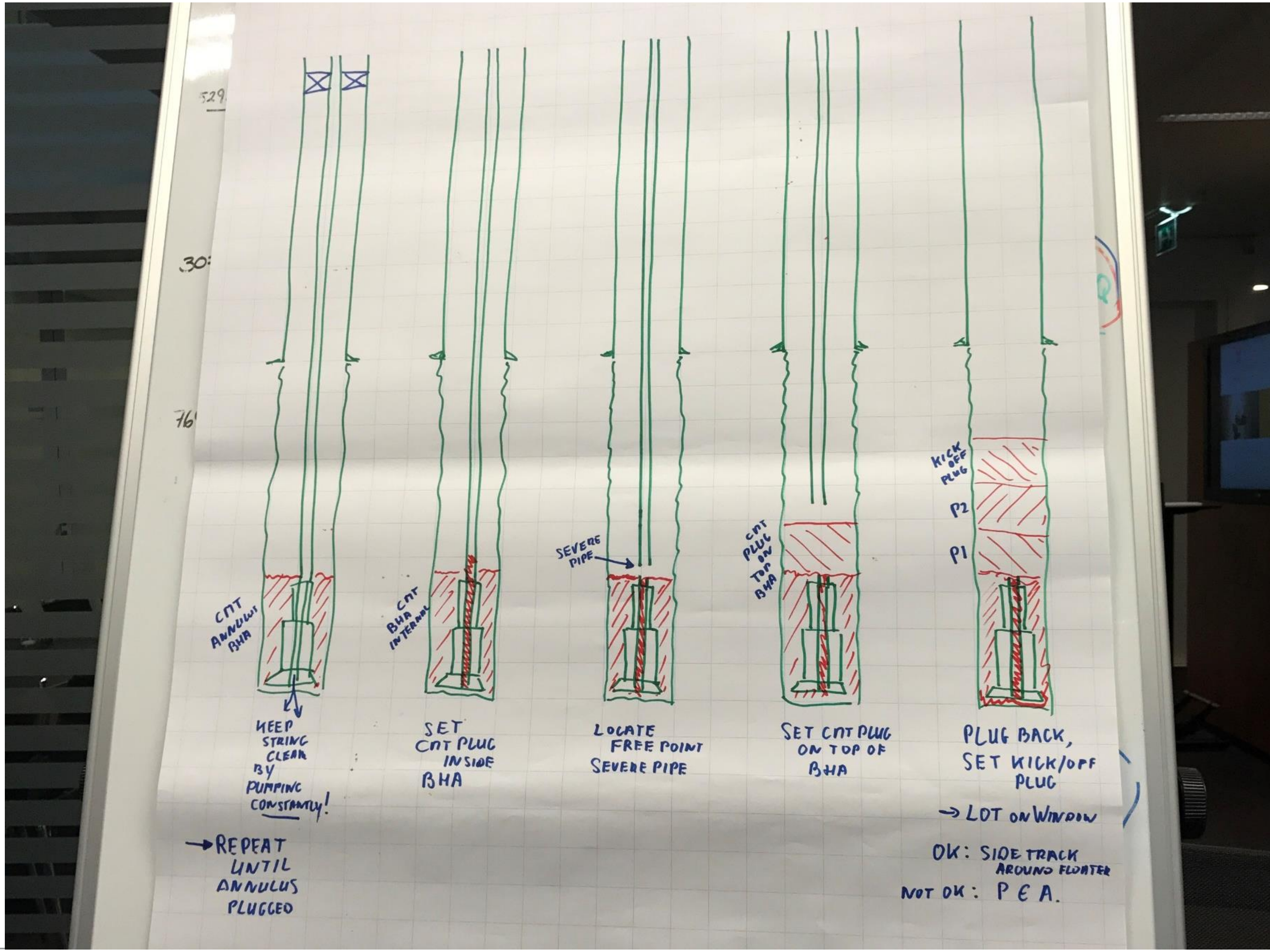
N05-01-S2 Zechstein kick summary

- 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

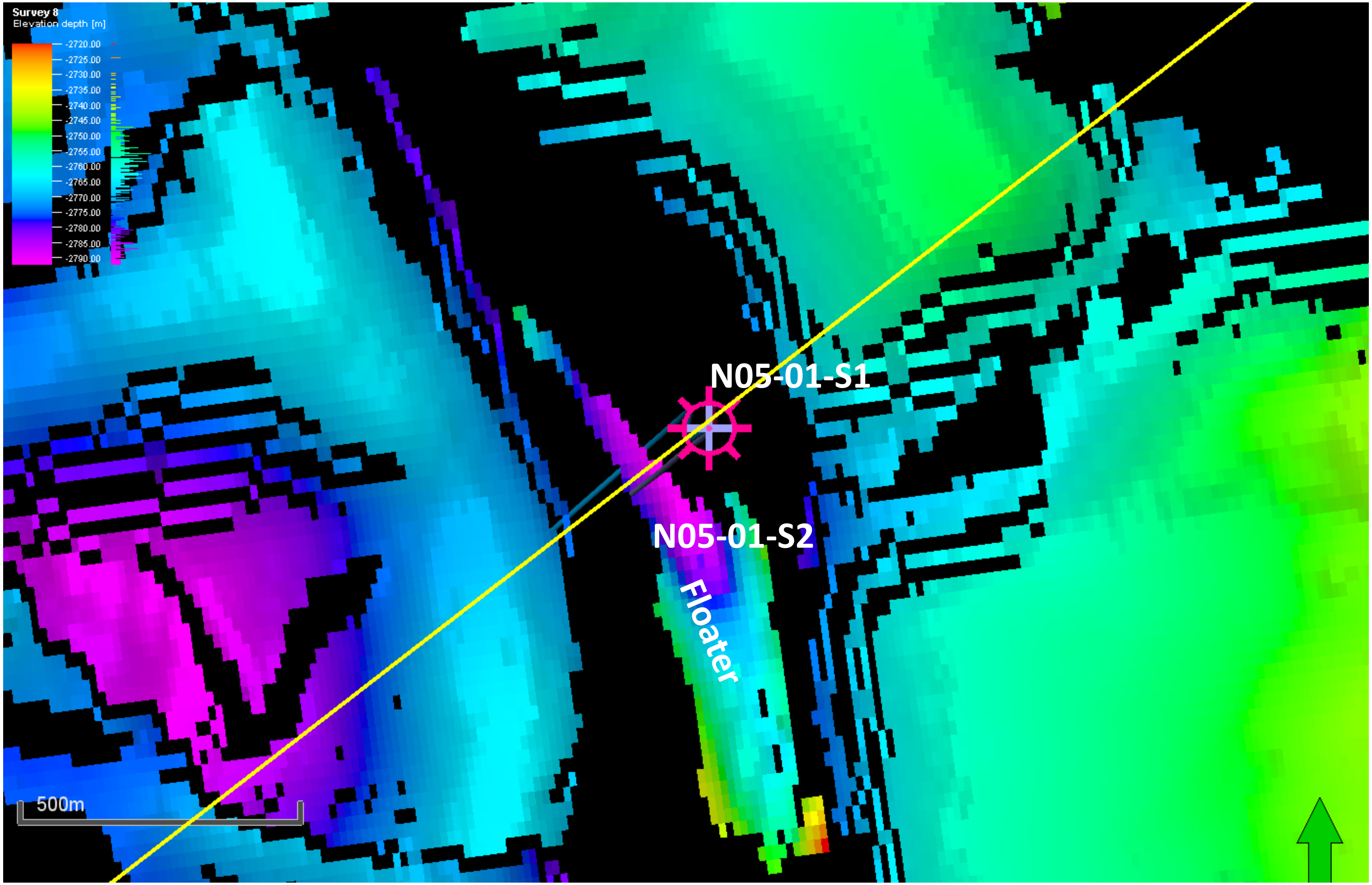




Five step plan to recover from kick

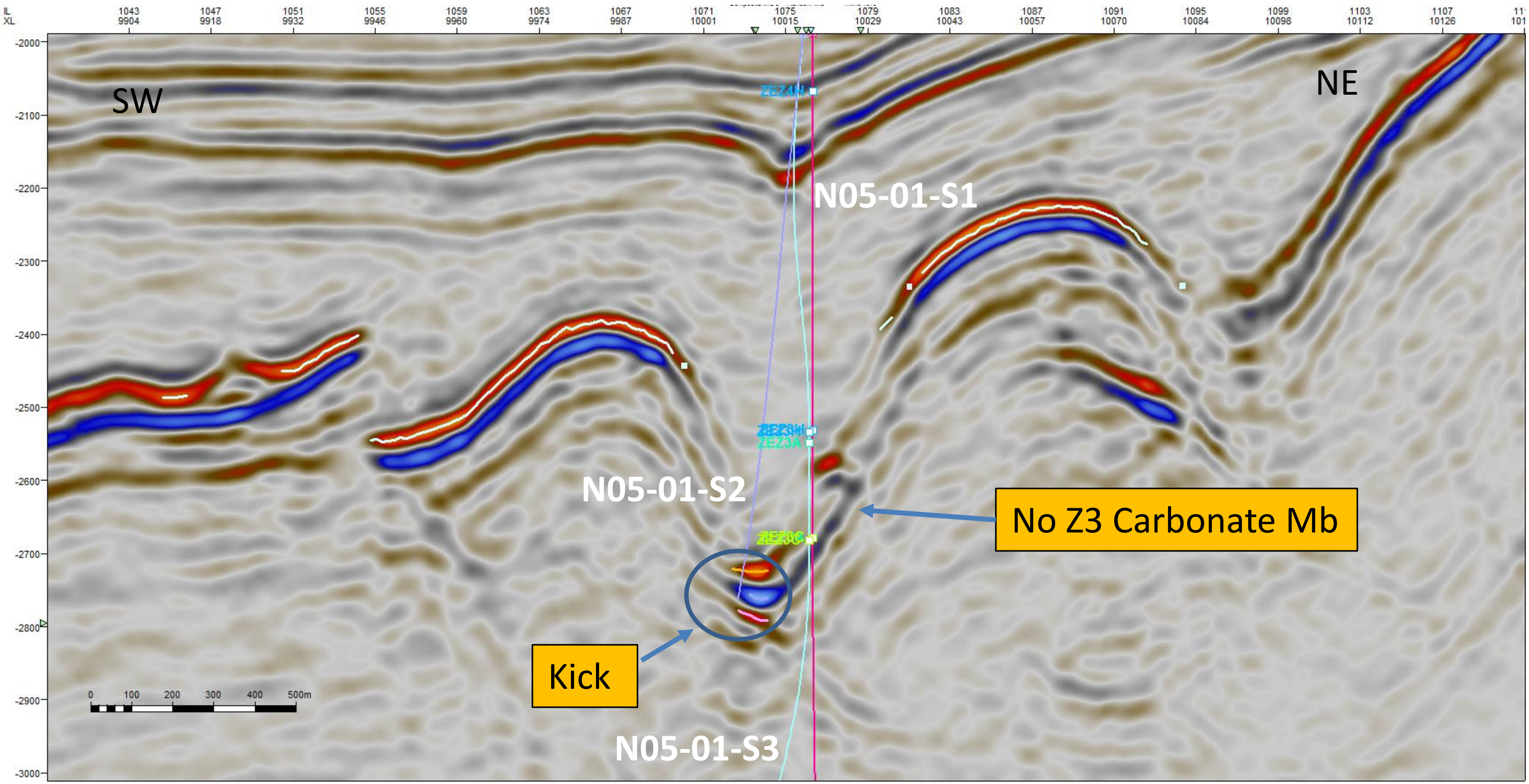


Syncline in Z3 Carbonate Mb, Floater Horizon



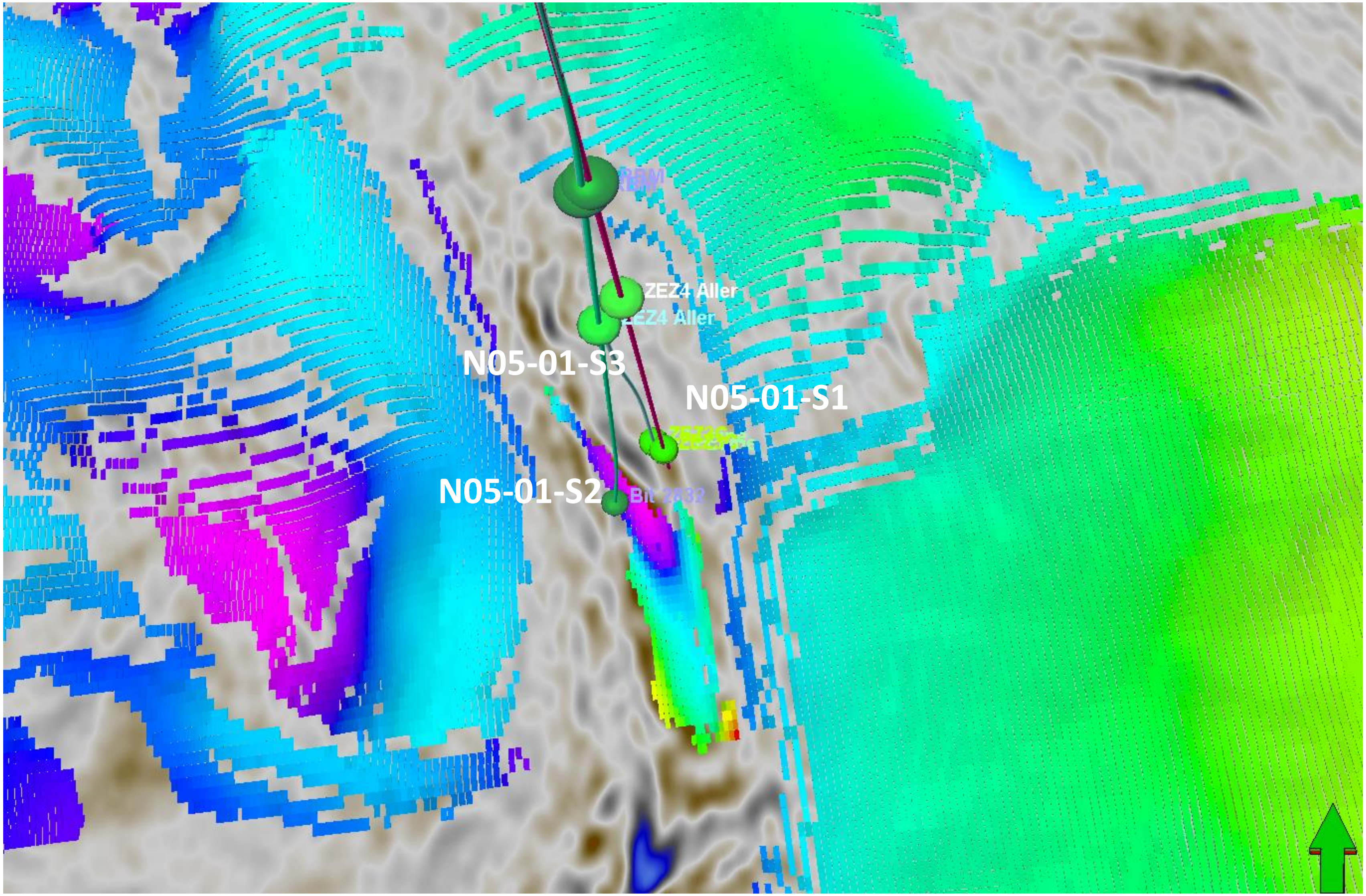
However N05-01-S2 unexpectedly found a floater

Trough and Kick Horizon, ST Version R2.0



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

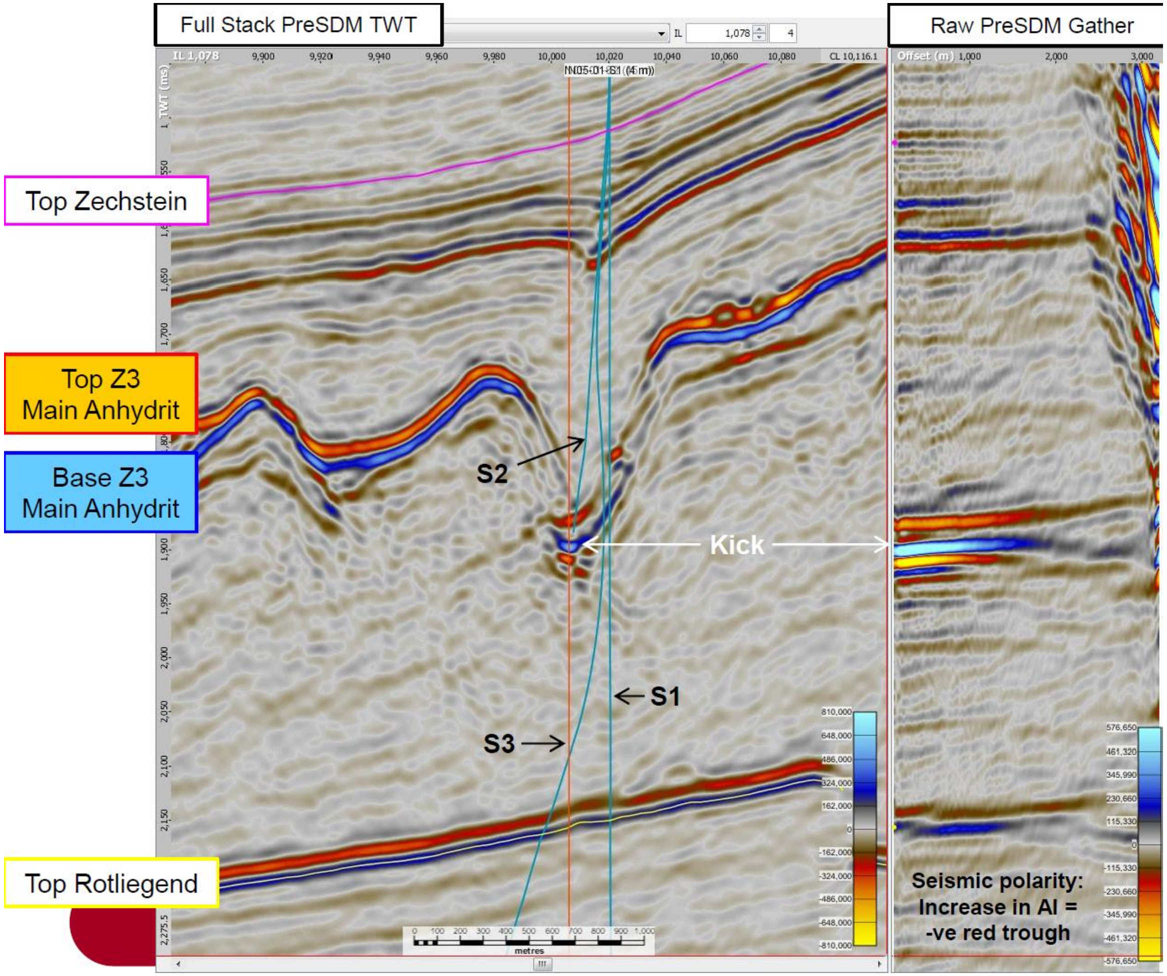
Z3 Carbonate Mb Trough and Kick Horizon, 3D View



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.

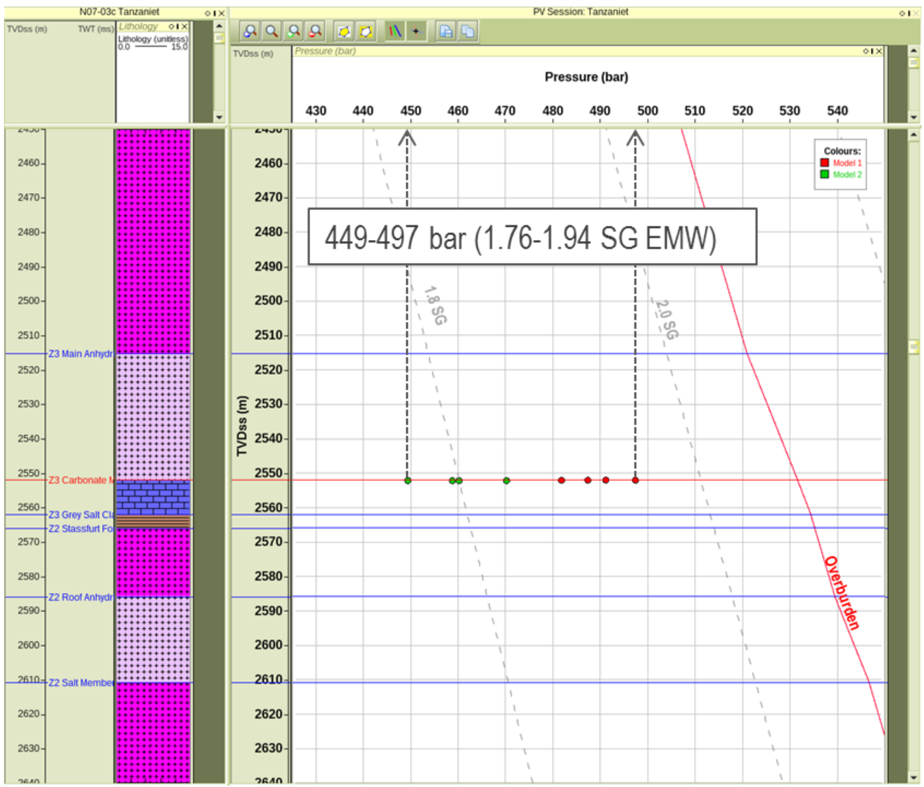
Post well analysis

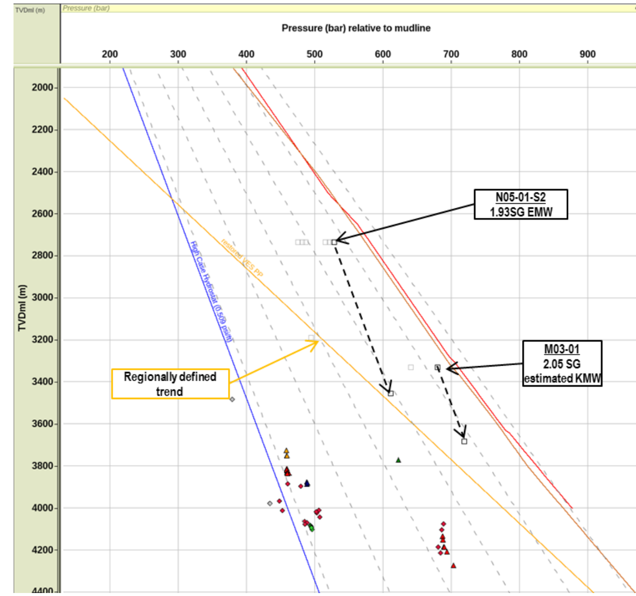
- N05-01-S1 experienced no kick, no Z3 Carbonate, instead ~150m Z3 Main Anhydrite was encountered
- N05-01-S2 experienced a kick of ~1.93 SG EMW after drilling ~60m through Z3 Main Anhydrite
- N05-01-S3 experienced no kick, similar geology with N05-01-S1
  - 25m lateral from original hole

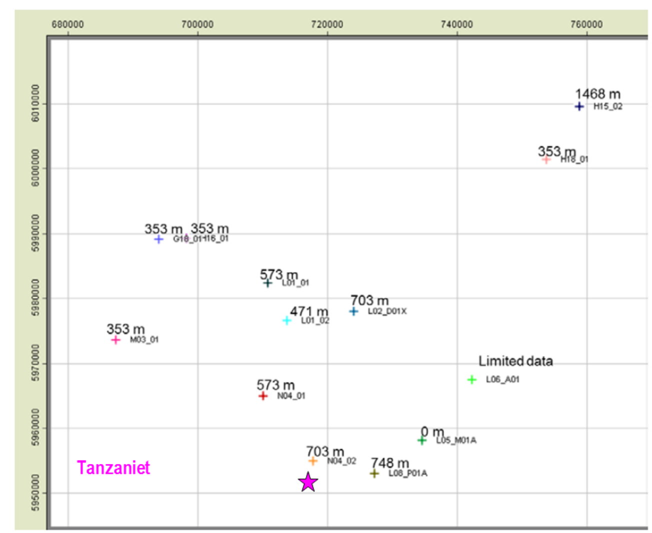


Semi-regional pore pressure model

- 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

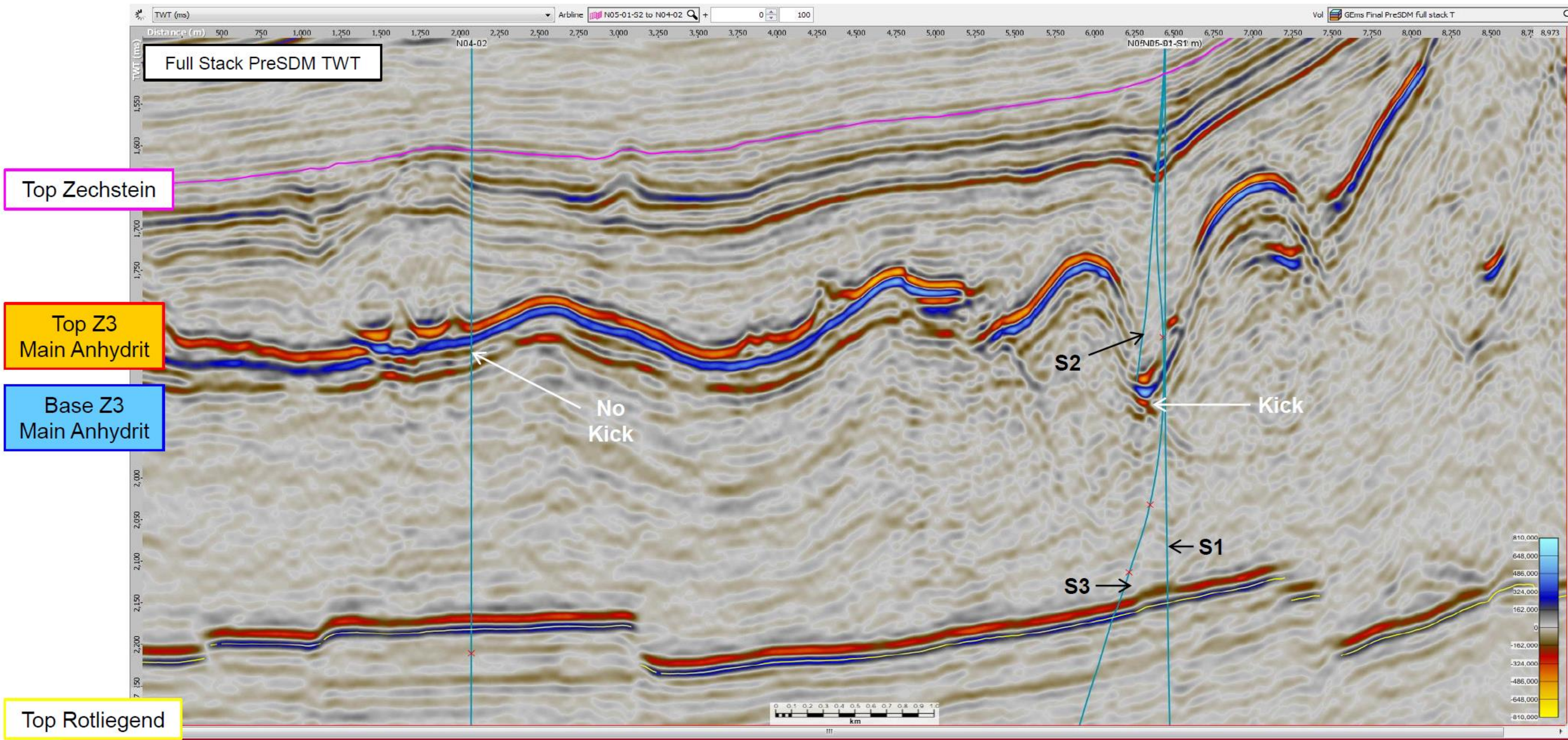
- Can seismic bright spots be used as a predicting tool for overpressured carbonate stringers?

- **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 proerties 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

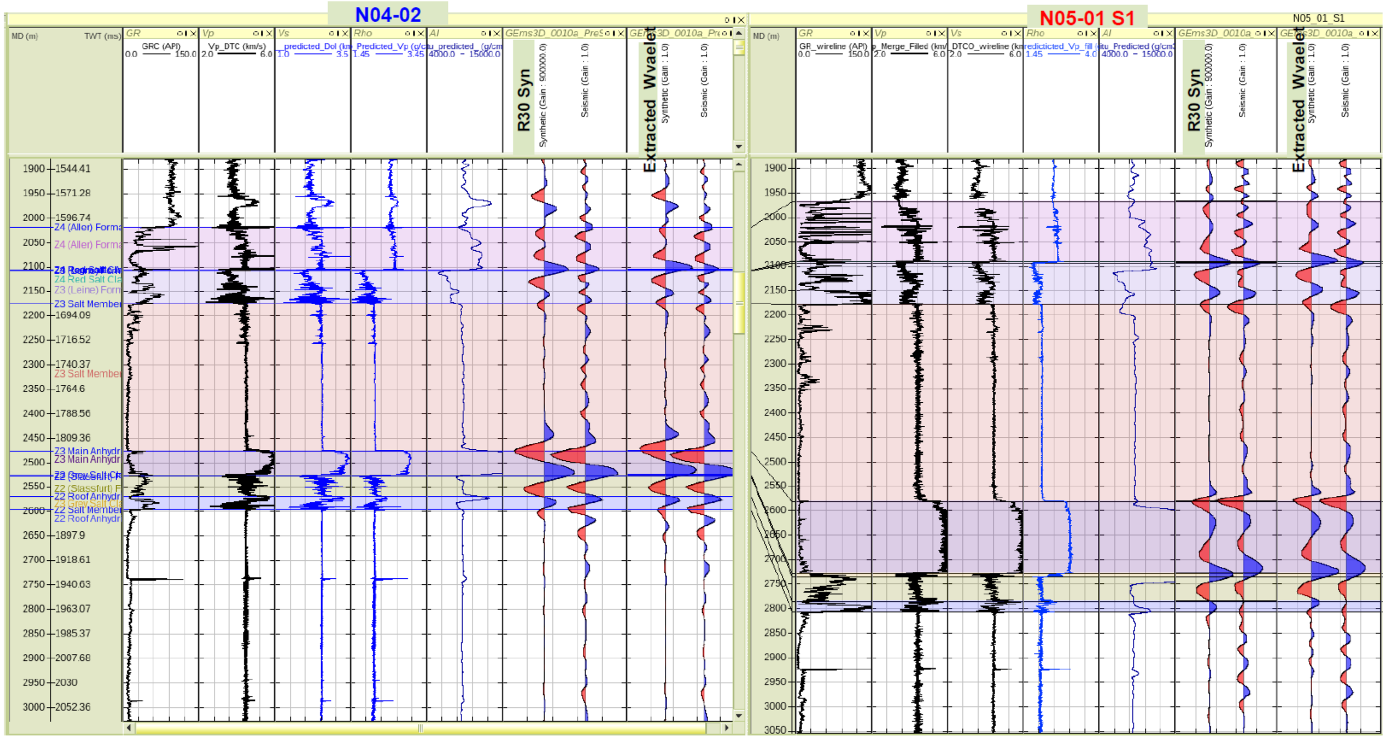
- Tuning effect is probable cause for high amplitudes at Z3 Main Anhydrite (main well, sidetrack and N04-02)
- Slight increase of reflectivity below Z3 Main Anhydrite might represent overpressure (avoid).

Seismic comparison with N04-02



The reflections at the top and base main anhydrite are generally bright

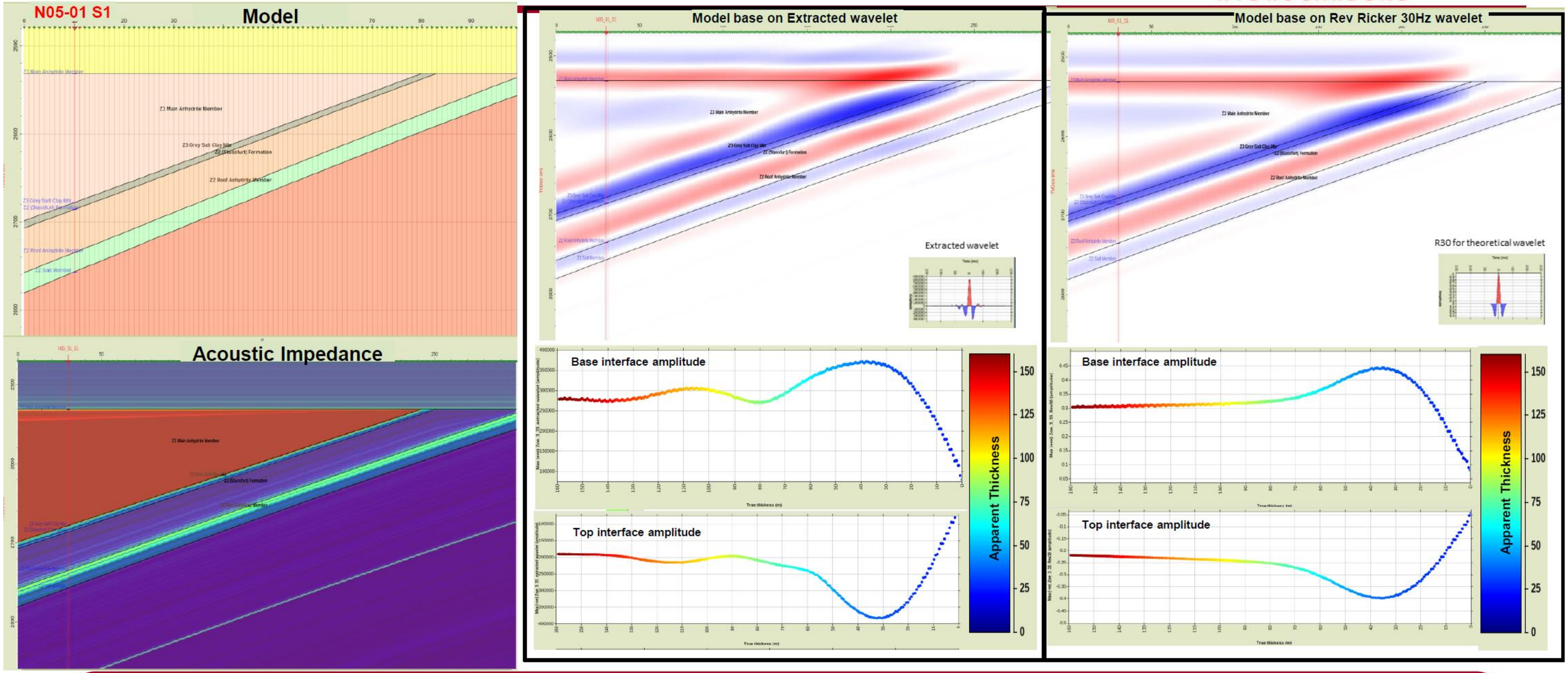
Zechstein well ties



The amplitude of the top and base main anhydrite reflection is much higher in N04-02.

Scenario I - Wedge based on Interpolated well data

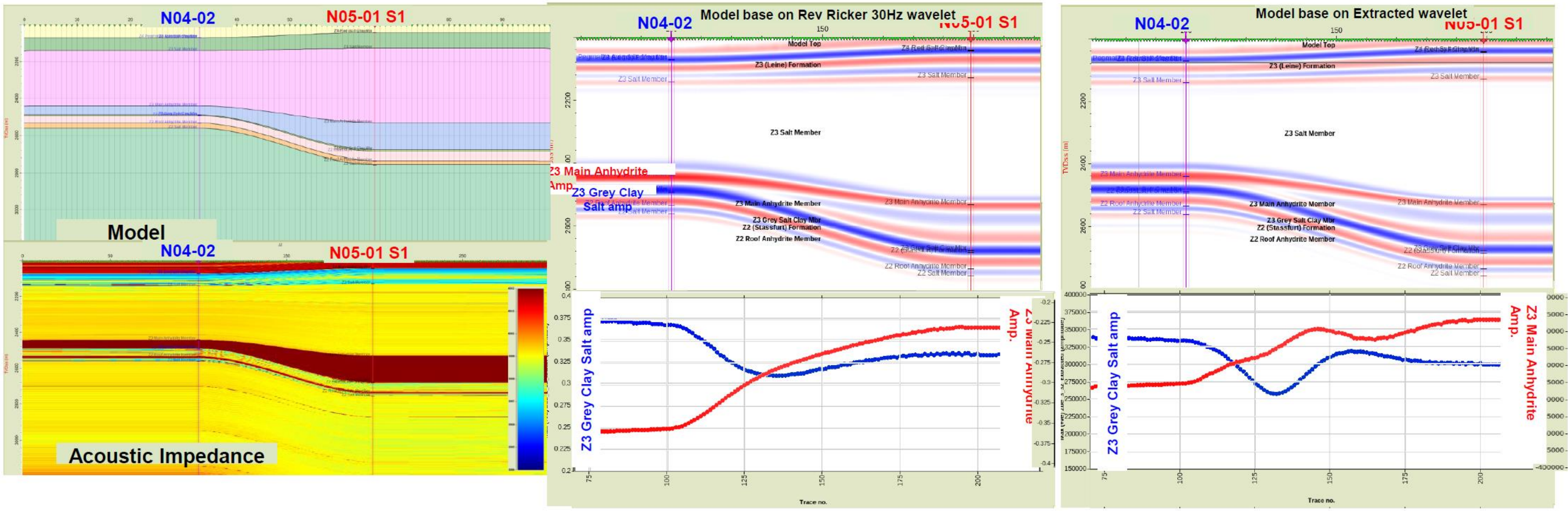
hansa HYDROCARBONS



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

hansa HYDROCARBONS

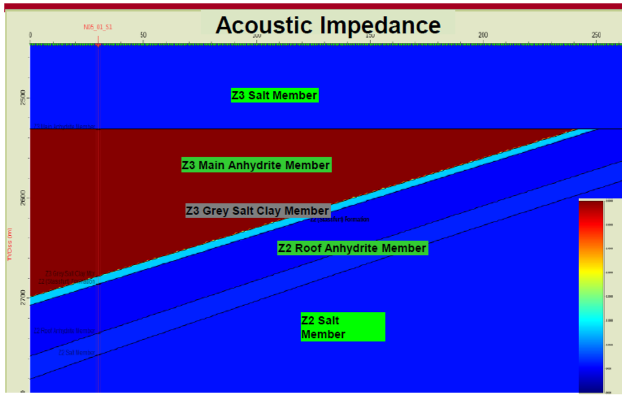


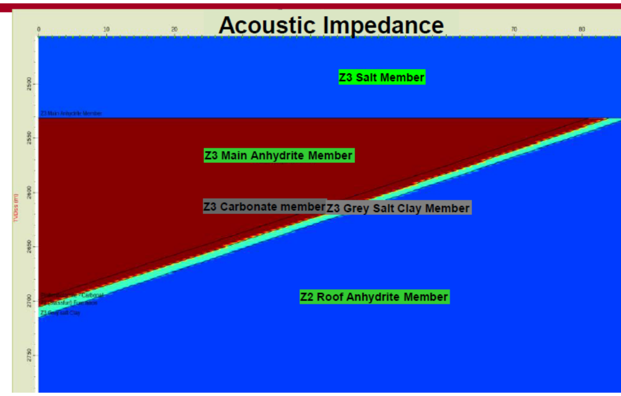
12% difference in base main anhydrite reflection between N05-01 and N04-02 due to tuning

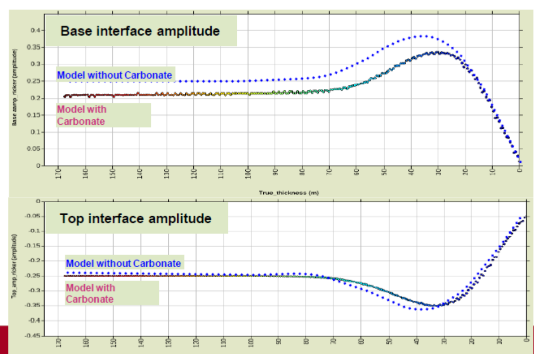
6

ORANJE-NASSAU ENERGIE

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

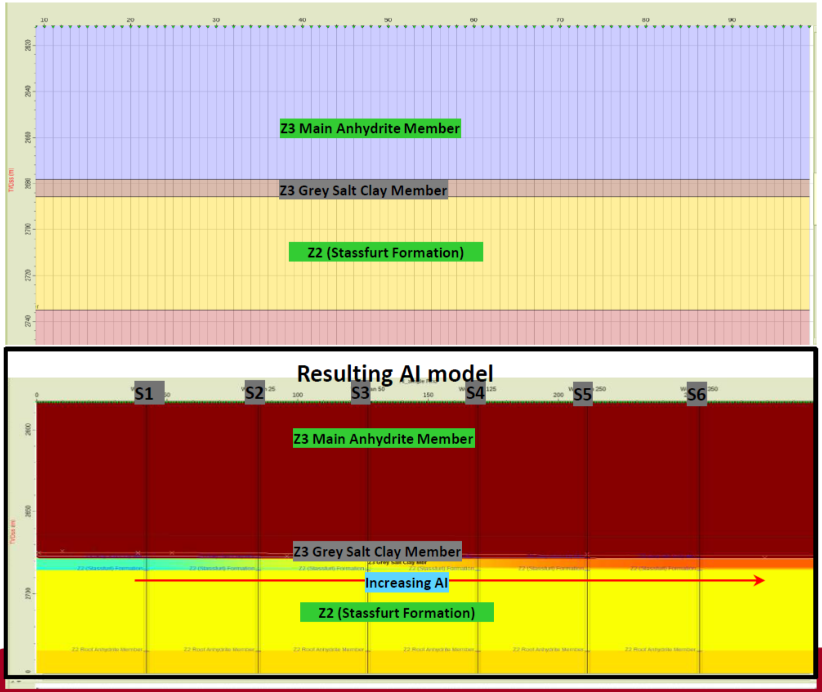
HYDROCARBONS

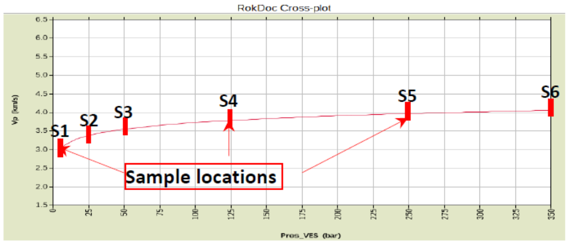
- Increasing pore pressure softens the elastic mineral frame by opening cracks and flaws, tending to lower velocities.
- Increasing pore pressure tends to make the pore fluid or gas less compressible, tending to increase velocities.
- Changing pore pressure can change the saturation as gas goes in and 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

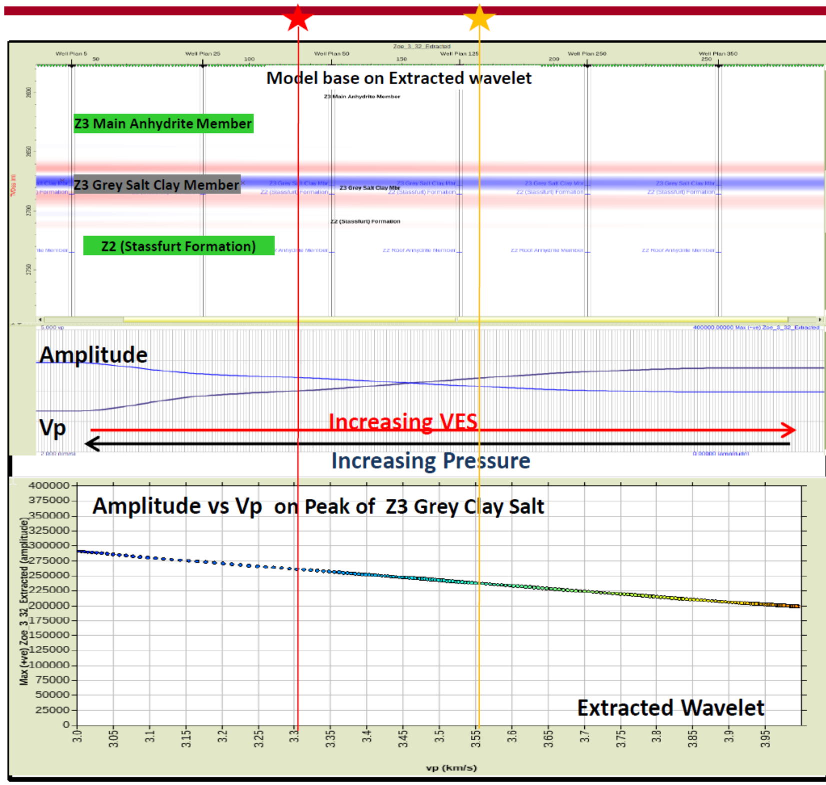
HYDROCARBONS

Six VES location 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

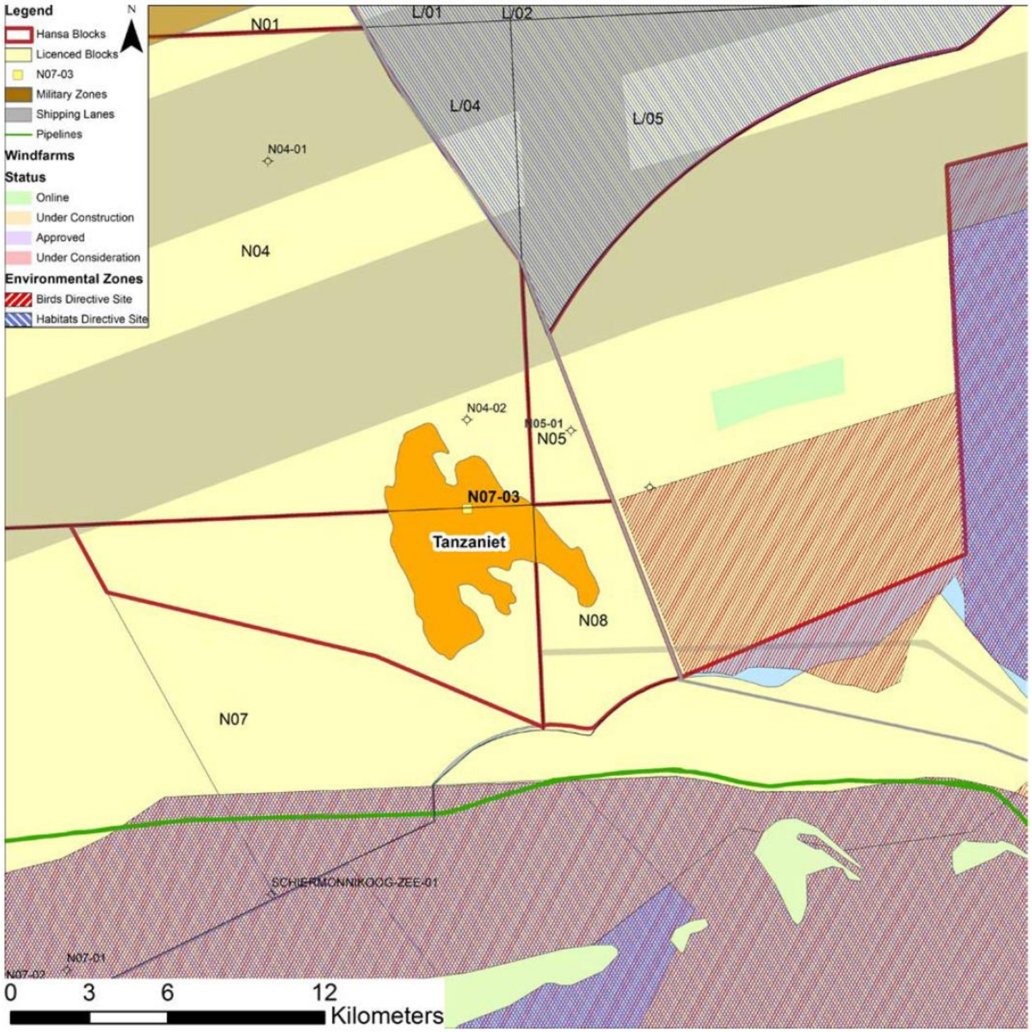


★ Typical effective stress at N05-01 well- 140bars
★ Calculated effective stress of kick 41.2 bars

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)

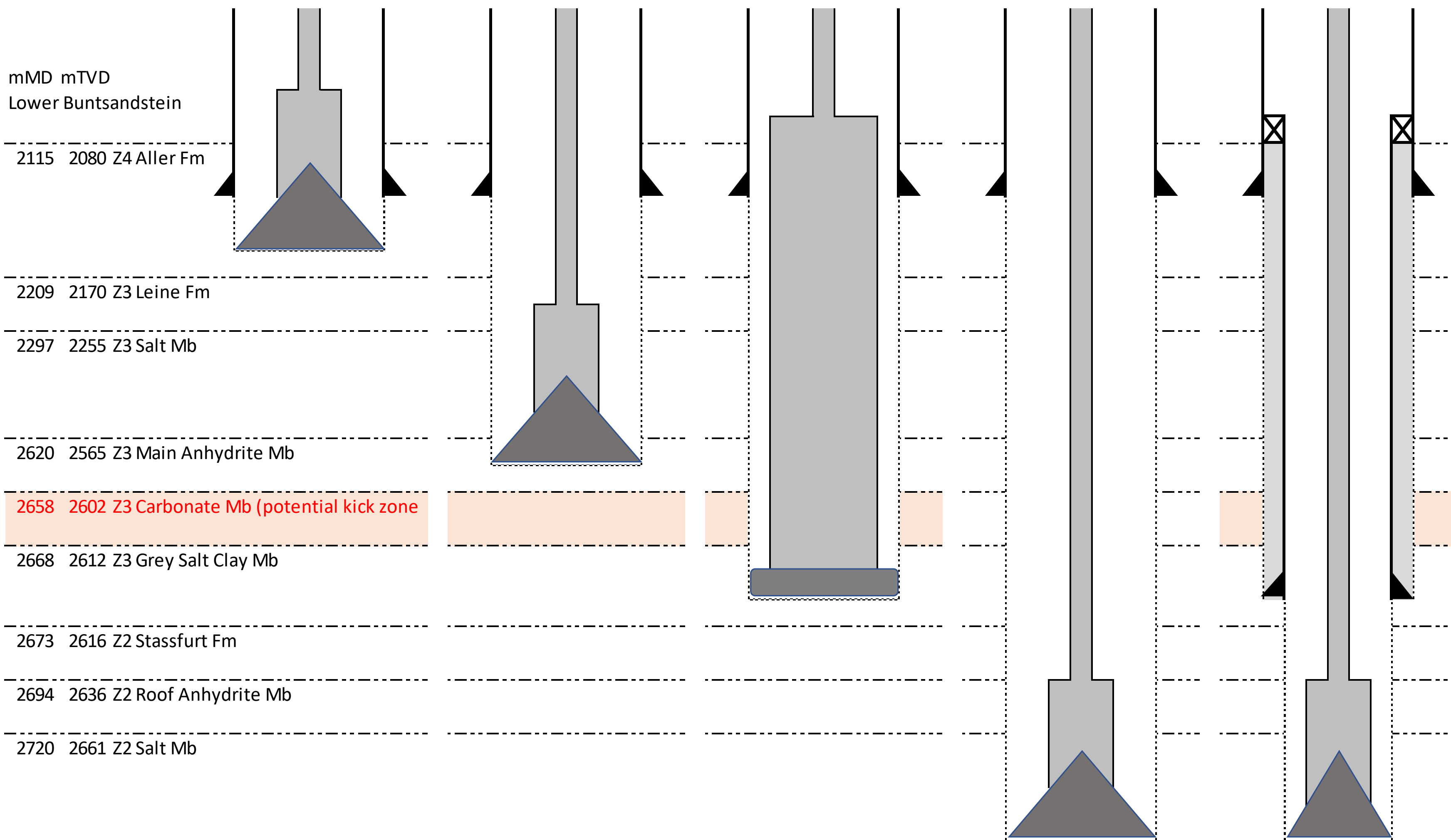
- Z3 Carbonate Member is a potential kick zone like in N05-01X, if present at all, and has an expected thickness of 10mTVD. **How to get through this zone?**

- 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

N07-04 Step plan visual

13 3/8" shoe installed in top Zechstein. Drill out 13 3/8" shoe and perform FIT (2.04sg).	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.



ORANJE-NASSAU ENERGIE