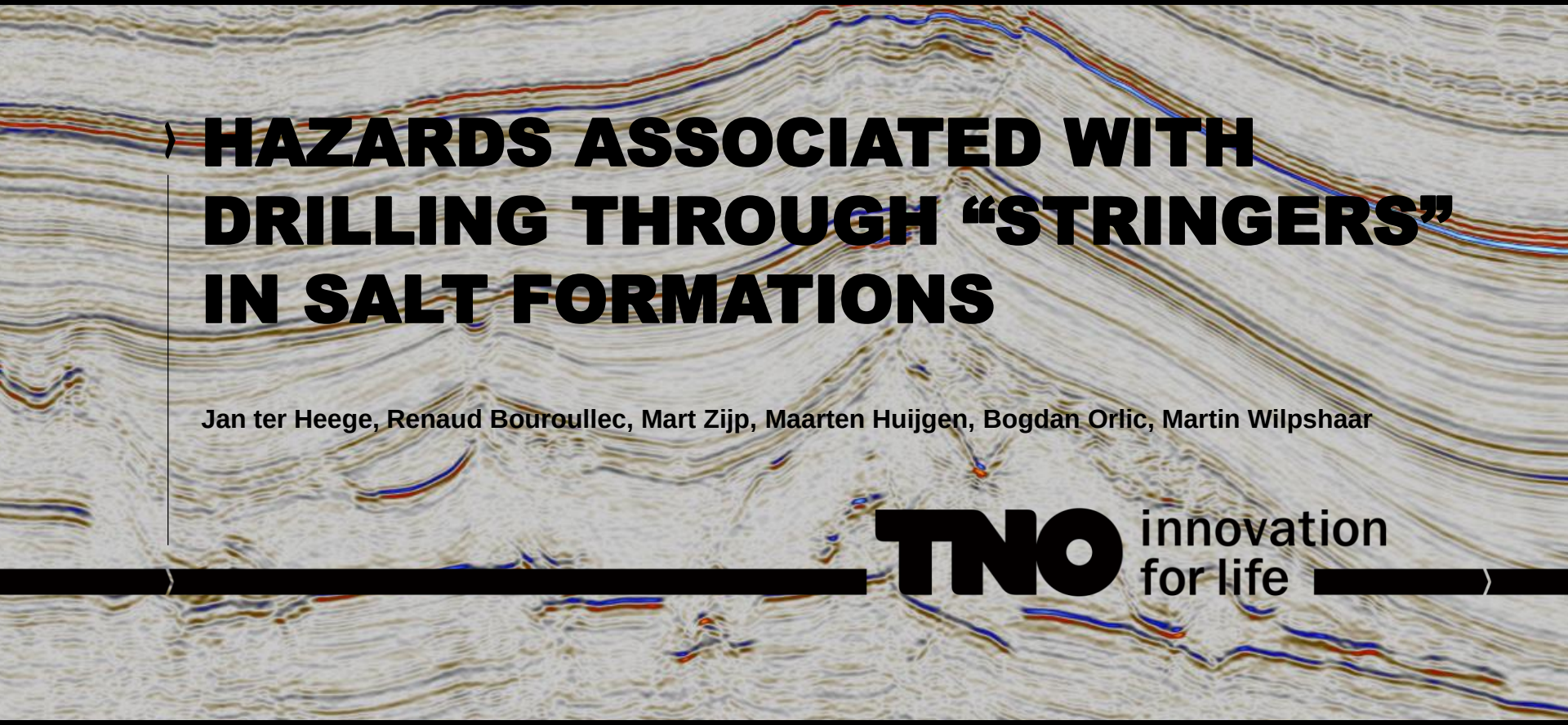


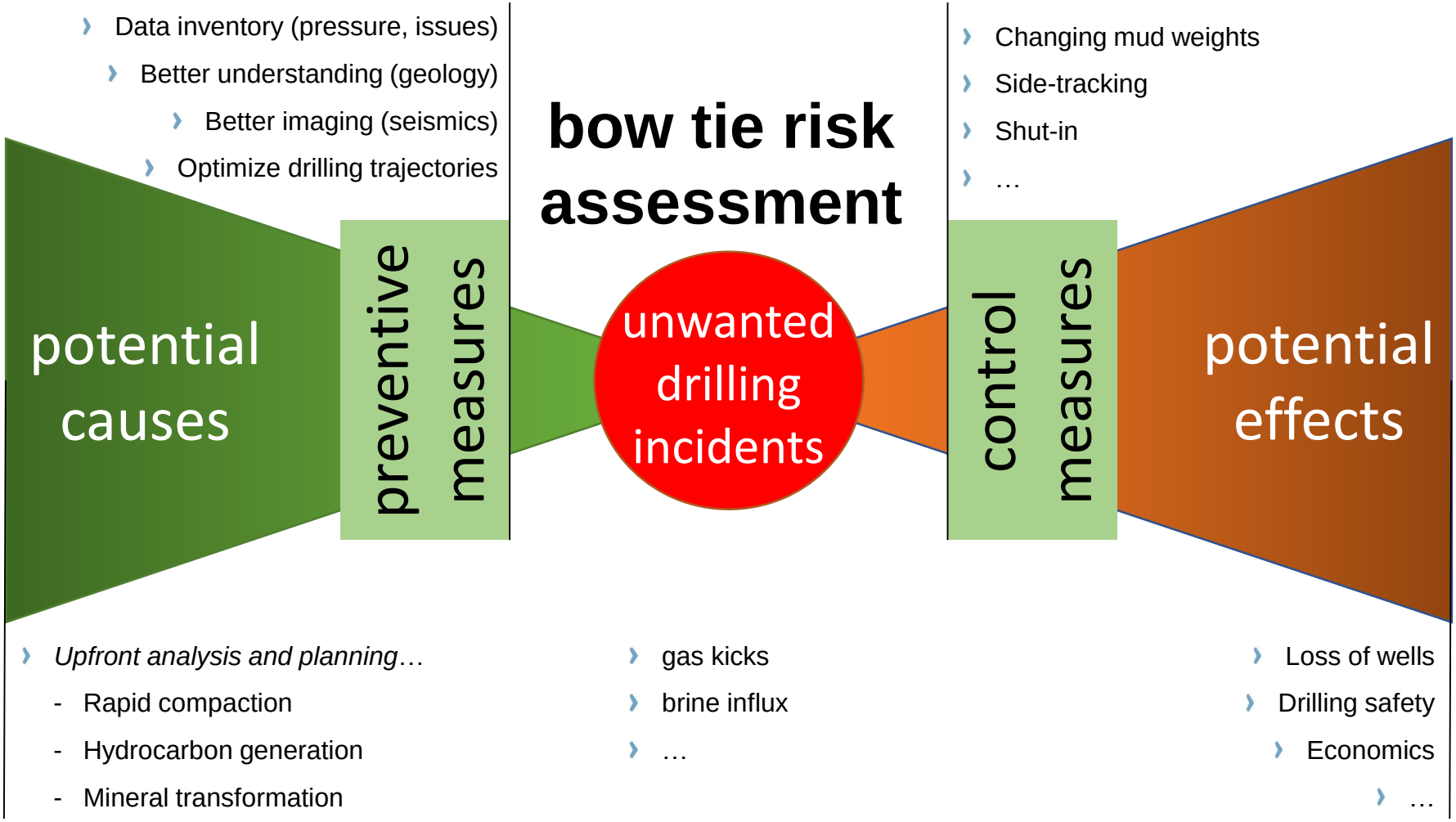
HAZARDS ASSOCIATED WITH DRILLING THROUGH “STRINGERS” IN SALT FORMATIONS

Jan ter Heege, Renaud Bouroullec, Mart Zijp, Maarten Huijgen, Bogdan Orlic, Martin Wilpshaar

TNO innovation for life

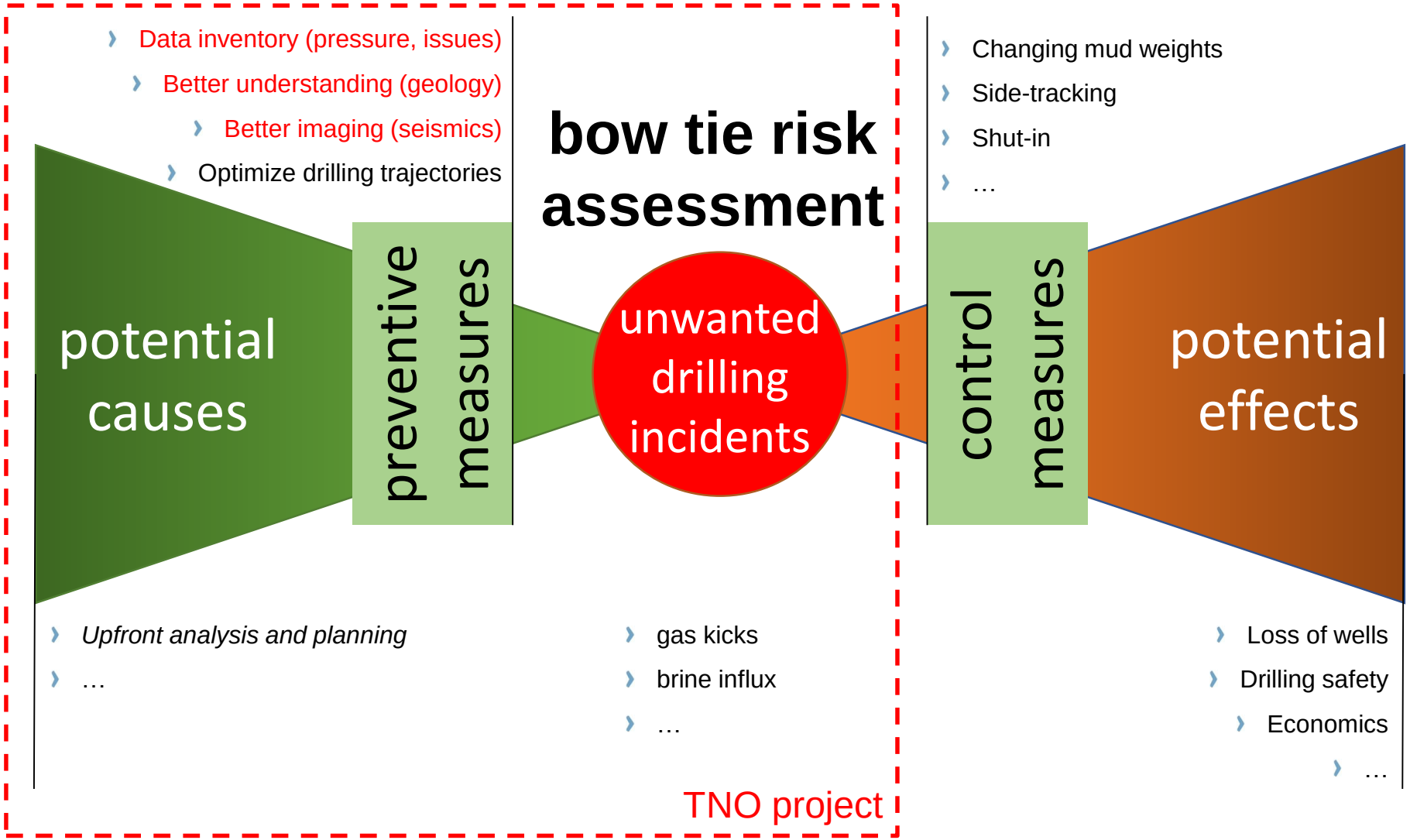
HANDLING DRILLING HAZARDS ASSOCIATED WITH STRINGERS IN SALT

TNO innovation for life



HANDLING DRILLING HAZARDS ASSOCIATED WITH STRINGERS IN SALT

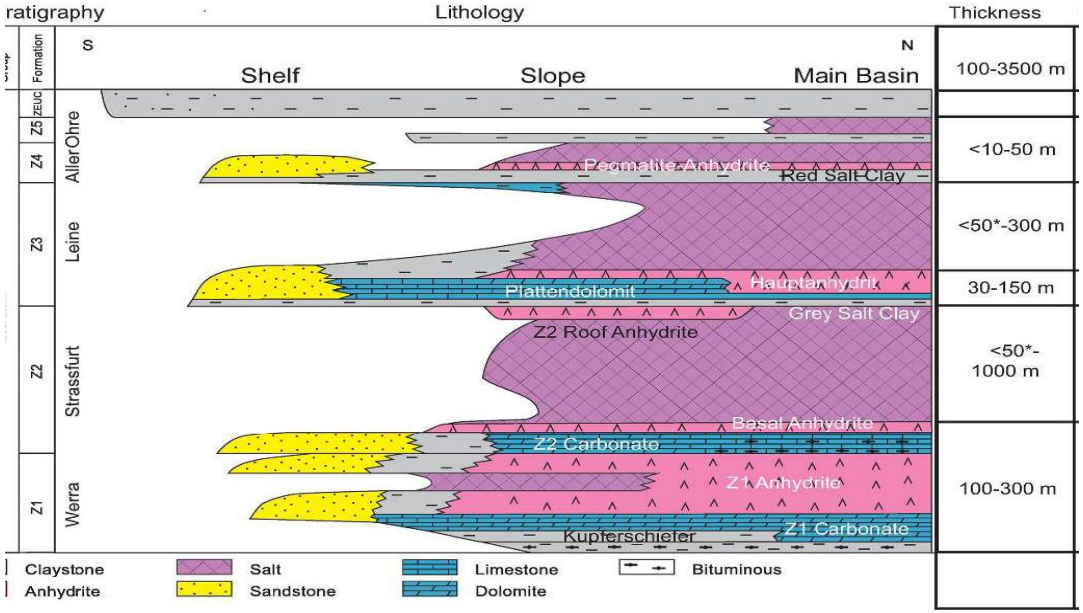
TNO innovation for life



GEOLOGICAL DESCRIPTION SHOWS MANY ANHYDRITE-CARBONATE (Z3AC) STRINGERS

Lithology Zechstein stringers

- 15–130 m thick **Hauptanhydrite (Z3A)** at the top
- 0.5–20 m thick **Platy Dolomite Member (Z3C)** in the middle
- 5-10 m thick **Gray Salt Clay** at the bottom
- Additional lithologies encountered:
  - Platform setting: grey microcrystalline dolomites and algal boundstones
  - Slope setting: carbonate mudstones, silty dolomites, oolitic and bioclastic grainstones
  - Basin setting: dark-coloured limestone



Modified from Geluk, 2007

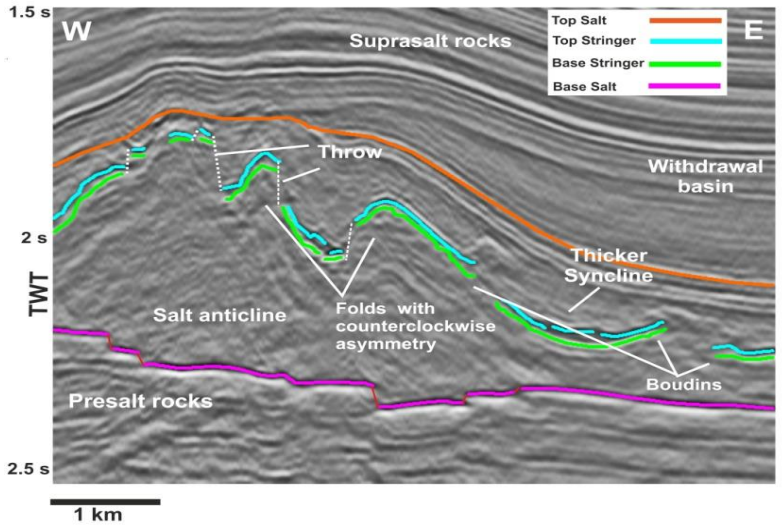
BETTER LOCATE AND CLASSIFY STRINGERS USING GEOLOGICAL RECONSTRUCTION

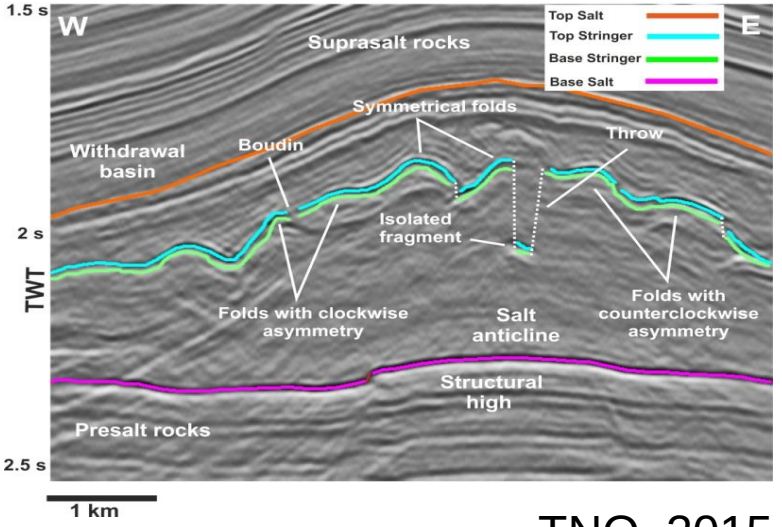
TNO innovation for life

Z3 Anhydrite-Carbonate stringers (Z3AC)

Geometry and distribution (*"Geological typing"*)

- Mainly located in the center to upper third of the salt section but some of the Z3AC fragments are grounded or close to base salt.
- Average thickness is 30–50 m with some spatially limited, blocky thickness anomalies of up to 150 m.
- Commonly broken into mappable fragments of varying size but are most likely still arranged along the deformed boundary between the Z2 and Z3 salt.
- Trend generally follows the shape of top Zechstein
- In some areas the salt and the imbedded Z3AC are almost undeformed (e.g., the Friesland Platform) while in other areas it is very fragmented (e.g., the Waddenzee).





TNO, 2015

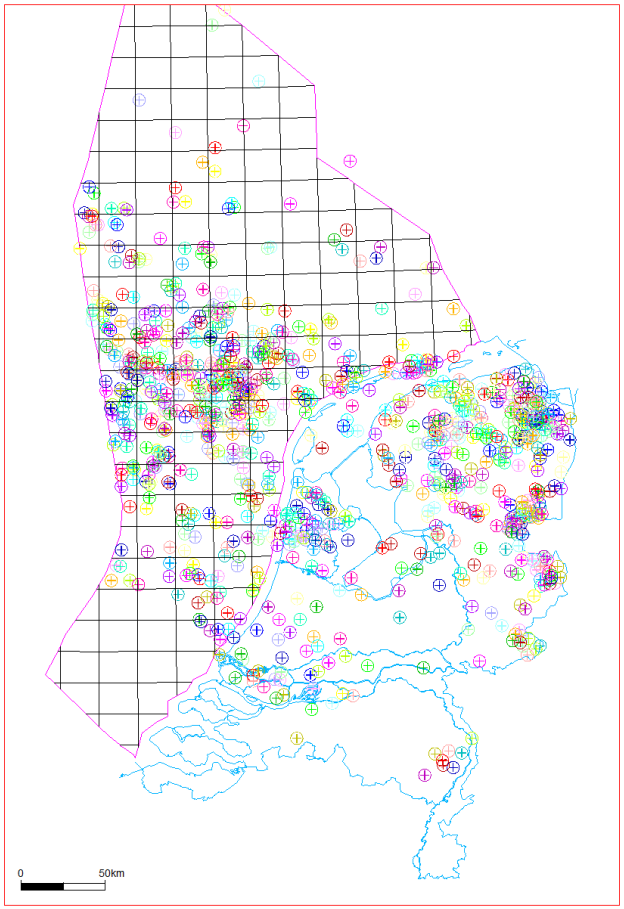
DATA INVENTORY OF STRINGER ISSUES & OCCURRENCES FOR DRILLING ZECHSTEIN

TNO innovation for life

Drilling the Zechstein in the Netherlands

- Inventory of total amount of wells in Zechstein stratigraphy
- Inventory of wells with pressure kicks in the Zechstein
- Investigation of origin of kick, stratigraphy, end of well reports, identify possible occurred problems
- Selection a number of case studies, these are to be investigated in depth
- Based on:
    - Kortekaas et al. (2013) *'Drilling Hazards Information System for the Netherlands – pilot project'*
    - Verweij & Hegen (2015) *'Integrated pressure information system for the onshore and offshore Netherlands- Final report'*
    - Hoetz et al. (2017) *'EBN Drilling Database'*
    - TNO (2018) *'Stringers in salt expert meeting'*

2575 wells drilled through Zechstein



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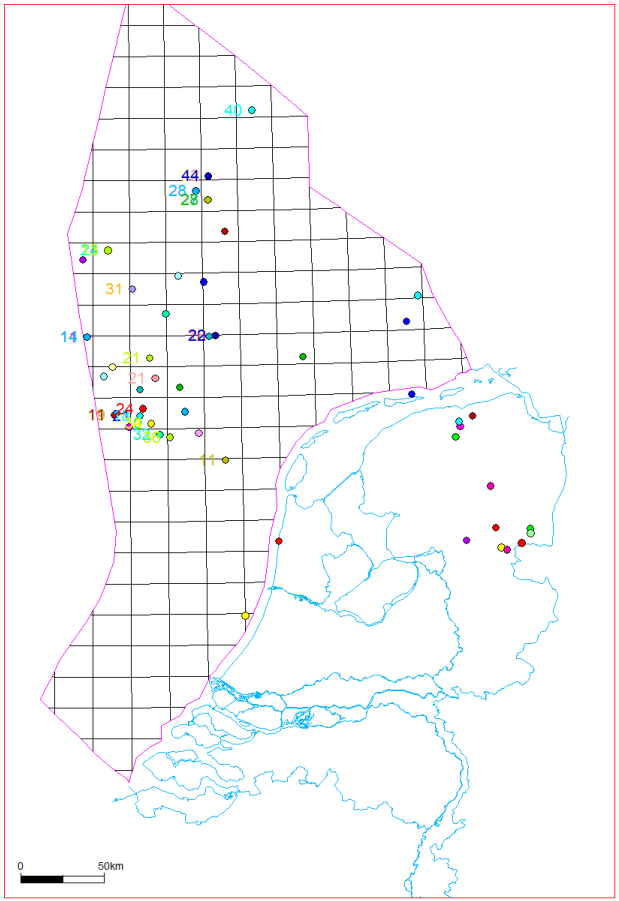
    - TNO (2018) *'Stringers in salt expert meeting'*

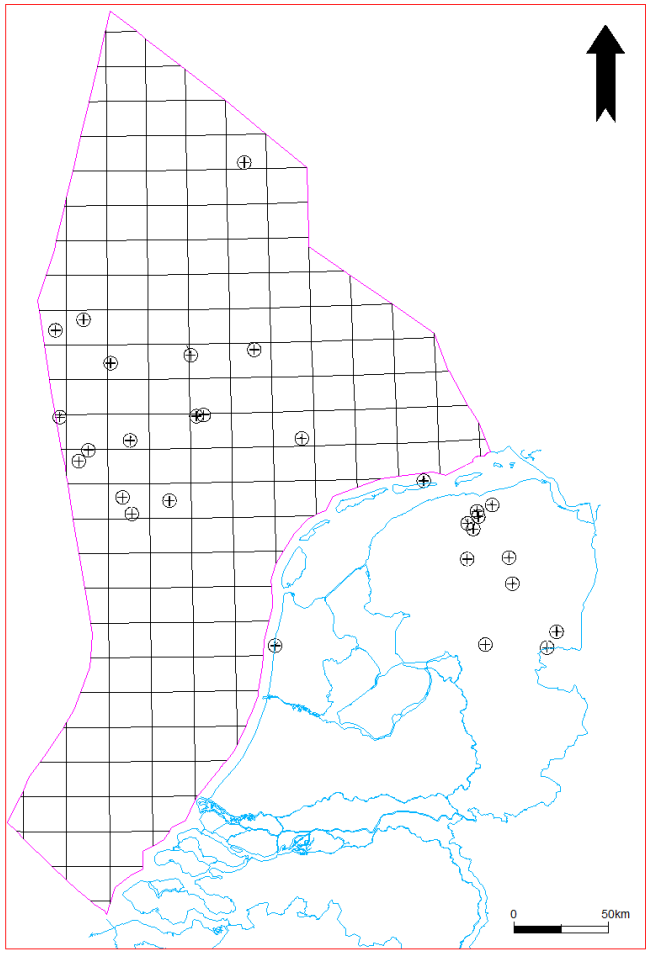
Pressure kicks or anomalous pressures in **62** out of **2575** wells

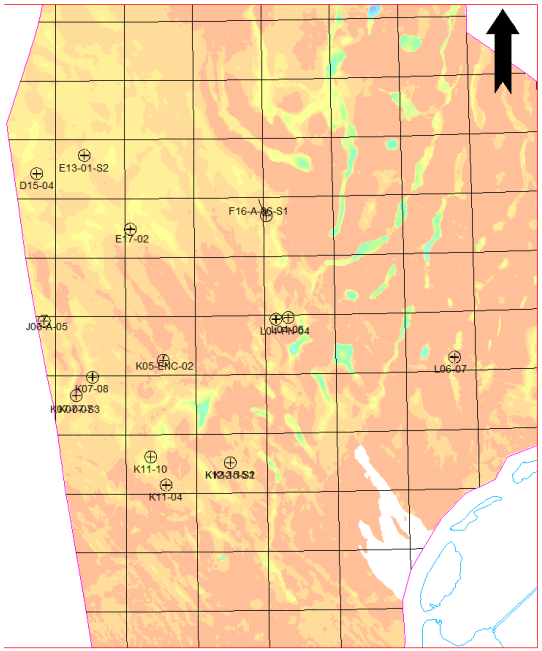


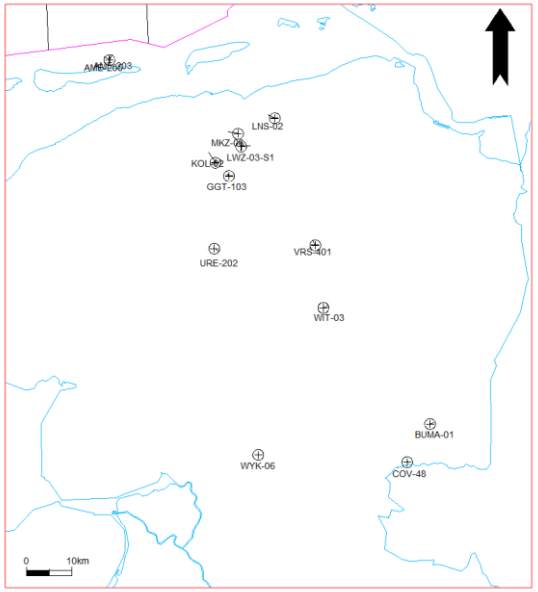
DATA INVENTORY OF STRINGER ISSUES & OCCURRENCES FOR DRILLING ZECHSTEIN

TNO innovation for life

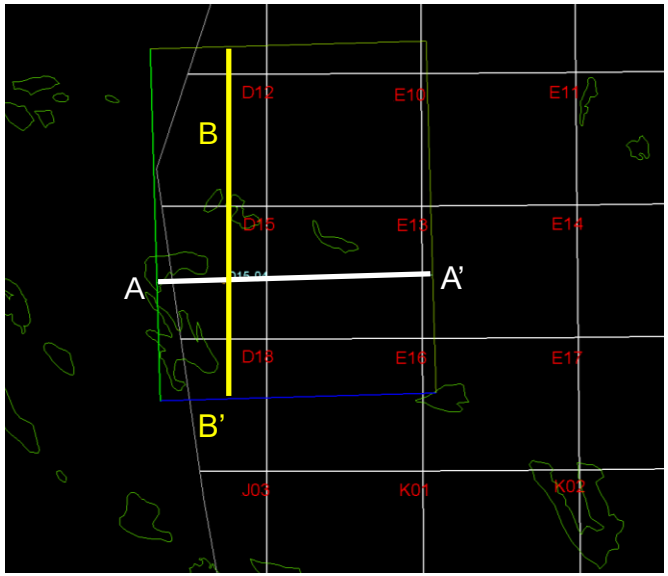
- All **62** wells with kicks were investigated using 3D seismics
- **45** stringers could be identified for wells with kicks

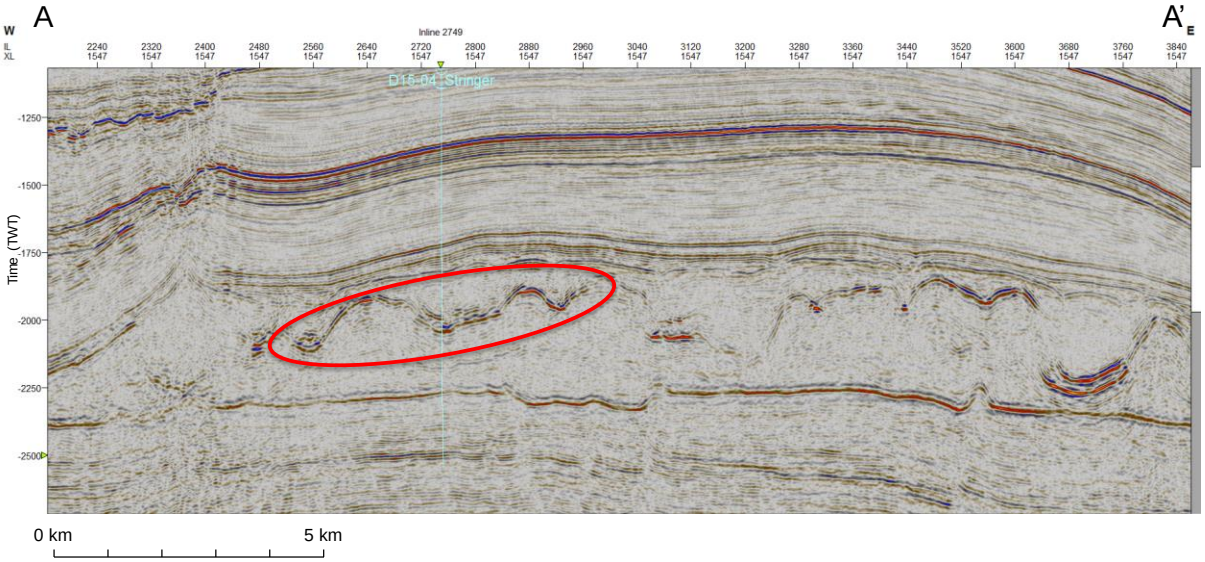


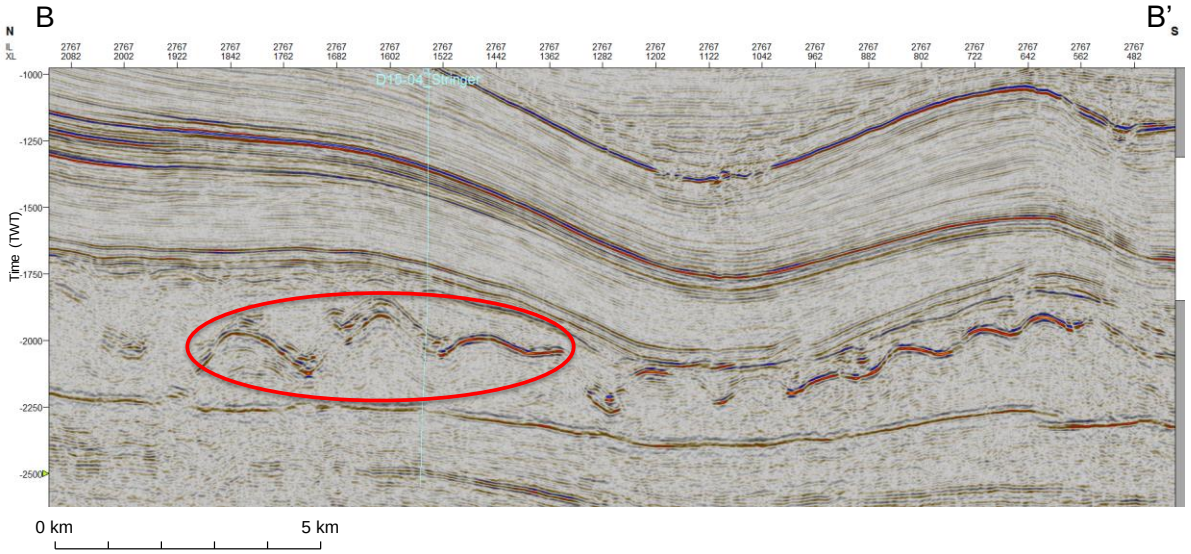




EXAMPLE OF STRINGER DRILLED BY WELL D15-04



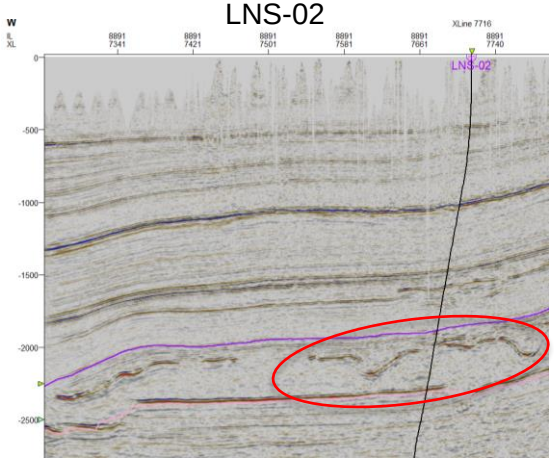




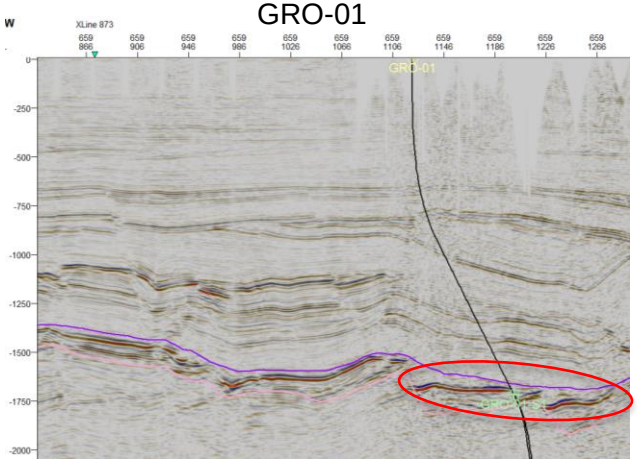
OTHER EXAMPLES OF DRILLED STRINGERS VISIBLE ON SEISMIC SECTIONS

TNO innovation for life

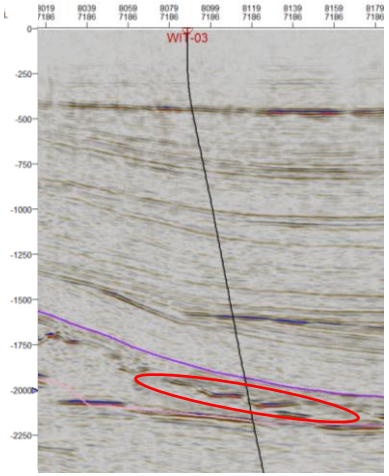
LNS-02



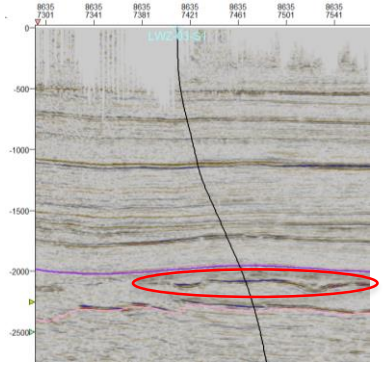
GRO-01



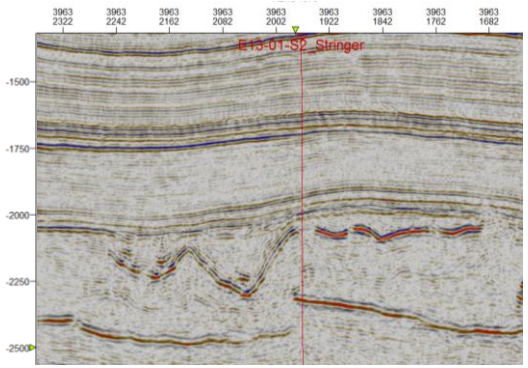
WIT-03



LWZ-03-S1



E13-01-S2



"Geological typing"

BETTER IMAGING OF STRINGERS TO BETTER RECONSTRUCT HISTORY AND PROPERTIES

TNO innovation for life

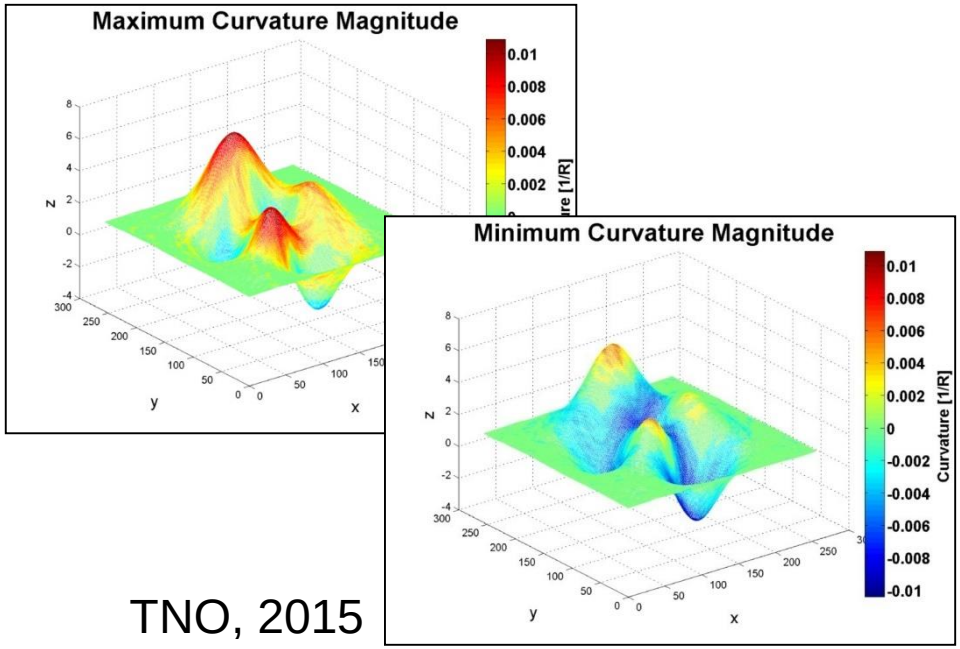
Z3 Anhydrite-Carbonate stringers (Z3AC)

Imaging

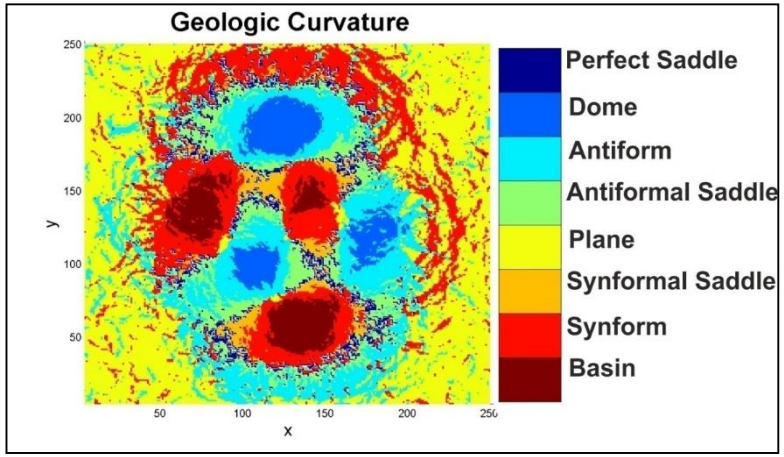
- Large acoustic impedance contrast between the Z3AC and the surrounding rock salt produces high-amplitude reflections.
- The high reflectivity allows continuous 3D tracking across very large areas.

Kinematics

- Z3AC was dragged along with the salt successive halokinetic movements.
- The Z3AC fragments that are physically isolated in the salt have been used as gauges of the rheology of the Zechstein salt (Li et al. 2017).
- Salt flows caused rupture and folding of the Z3AC on a wide range of scales.
- As the fragments travel through the salt during halokinetic movements, they fractured.



TNO, 2015

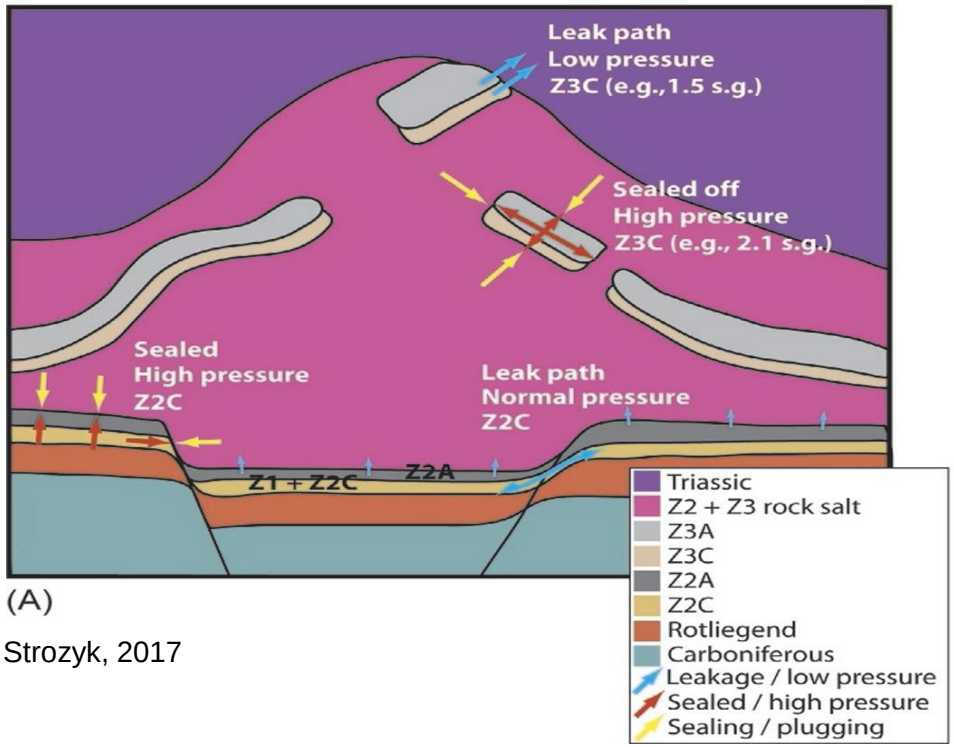


BETTER GEOLOGICAL CHARACTERIZATION TO CONSTRAIN PRESSURES IN STRINGERS

TNO innovation for life

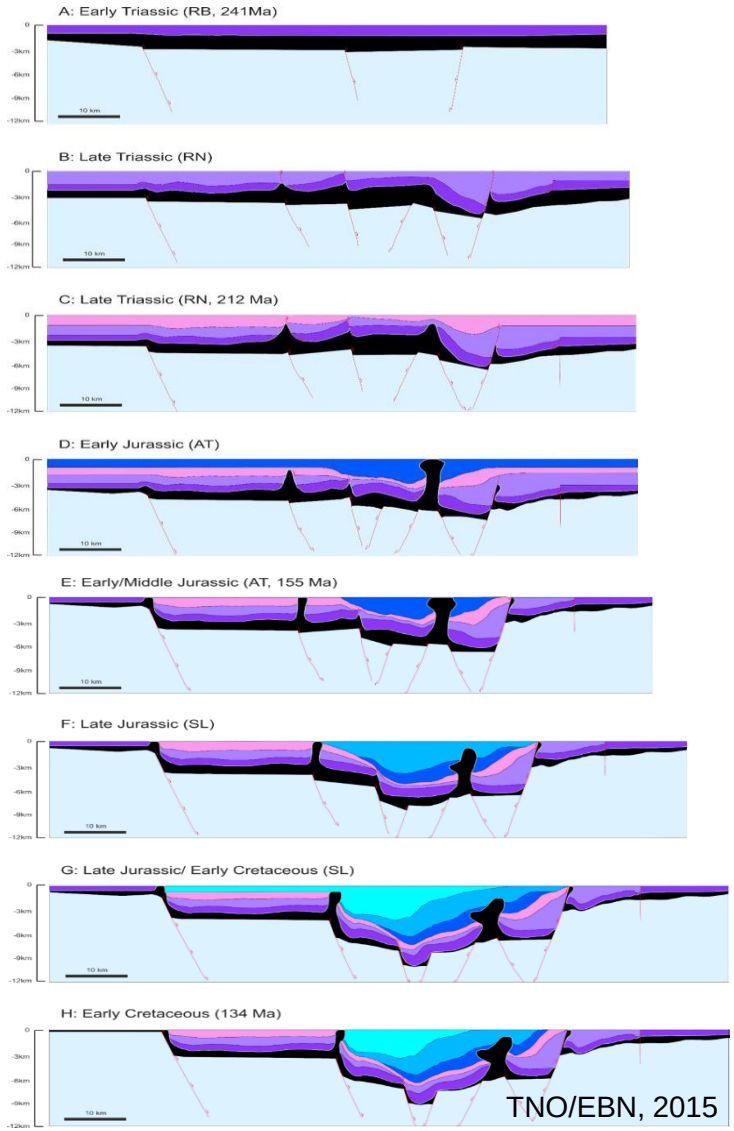
Attuned geological characterization

- New imaging techniques (e.g. stratal slicing, attribute mapping, …)
- New detail mapping of ZE and Z3AC
- 2D/3D structural restoration
- 3D petroleum system modeling for better evaluation of burial, erosional and paleostress history.



(A)

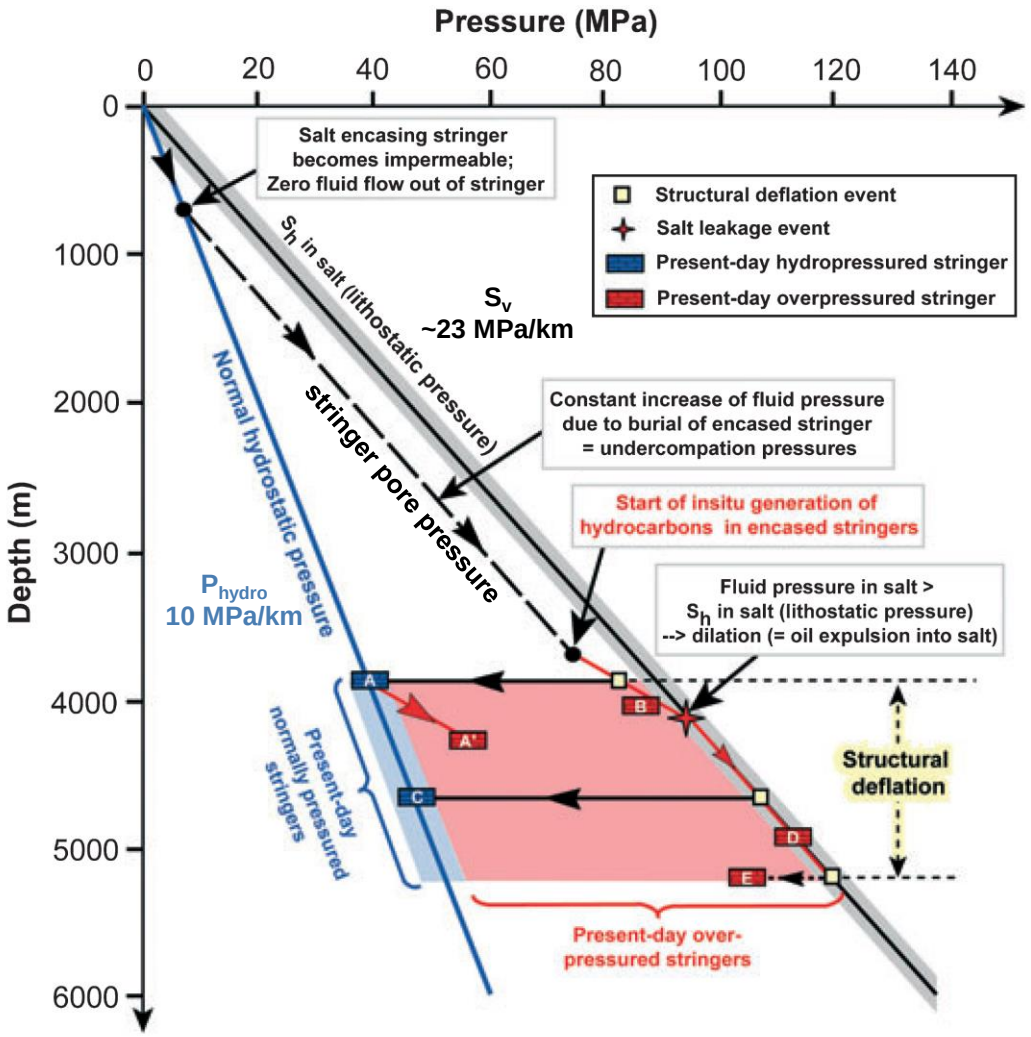
Strozyk, 2017



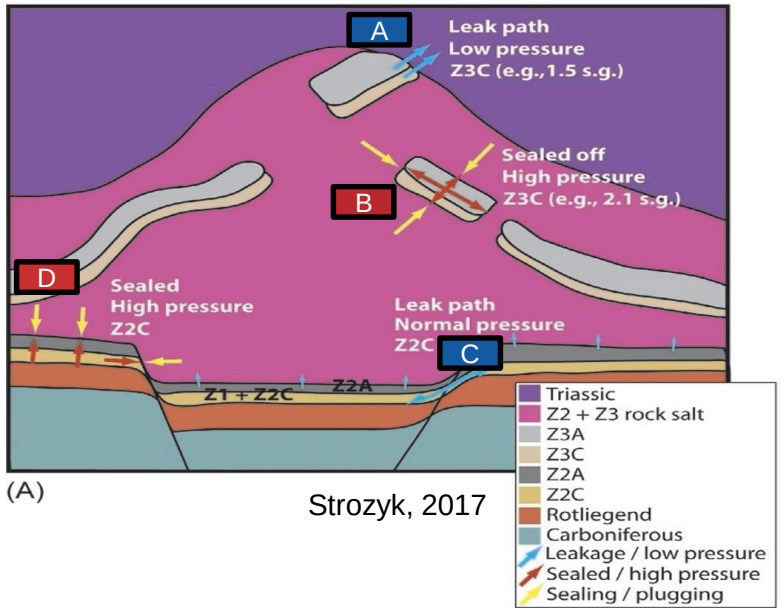
TNO/EBN, 2015

CONSTRAINTS ON MAXIMUM EXPECTED PORE PRESSURE IN STRINGERS

TNO innovation for life



- Location-specific stresses in NL can be calculated based on density and sonic logs
- Constraints in salt: log-based S_v; $S_v \approx S_h$; $P_p < S_h$



Strozyk, 2017

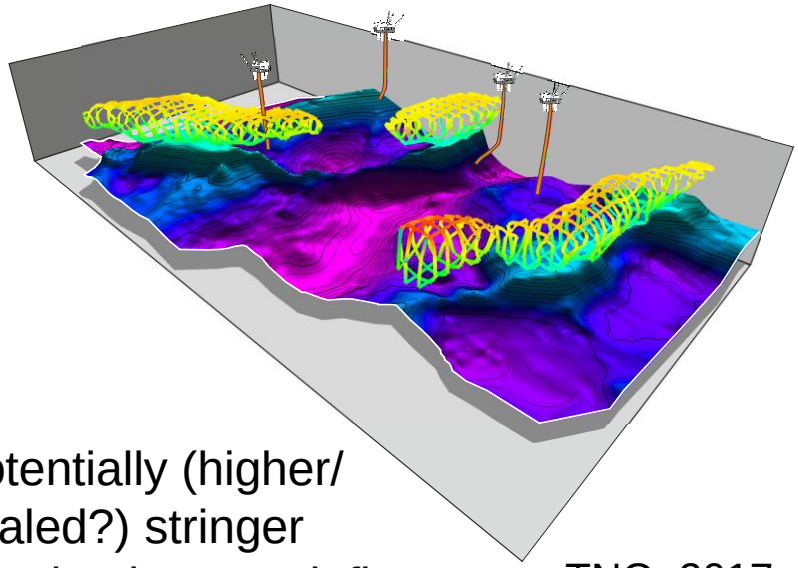
Analogue example for South Oman Salt Basin (Kukla et al. 2011)

Z3 Anhydrite-Carbonate stringers (Z3AC)

BETTER IMAGING TO LOCATE AREAS WITH POTENTIALLY ELEVATED DRILLING RISKS

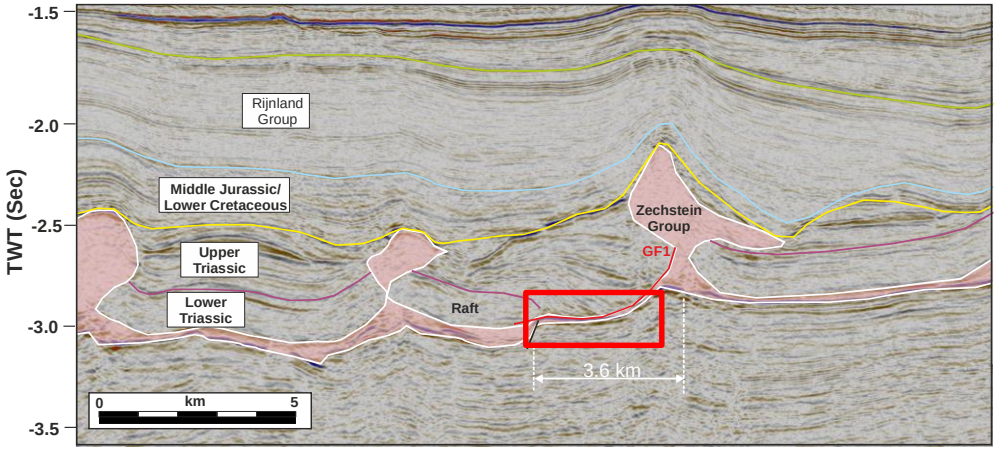
TNO innovation for life

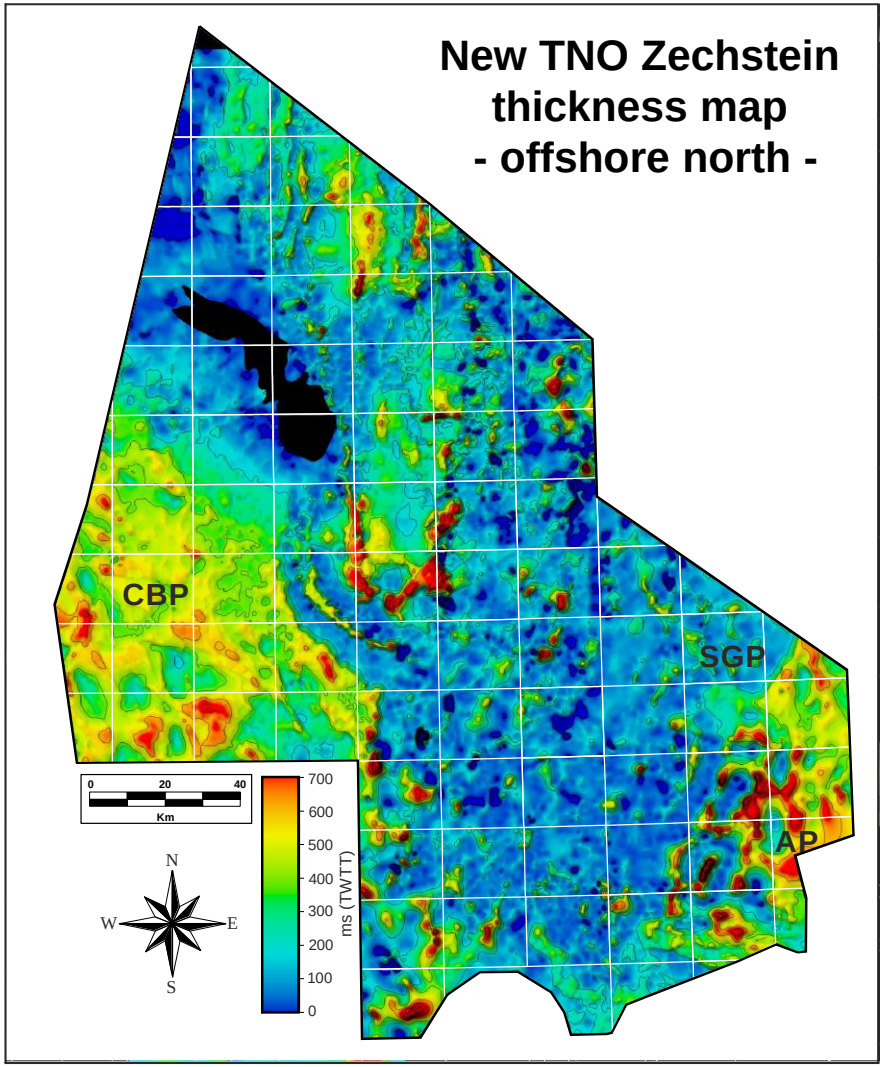
What is the relationship between salt welds and stringers?



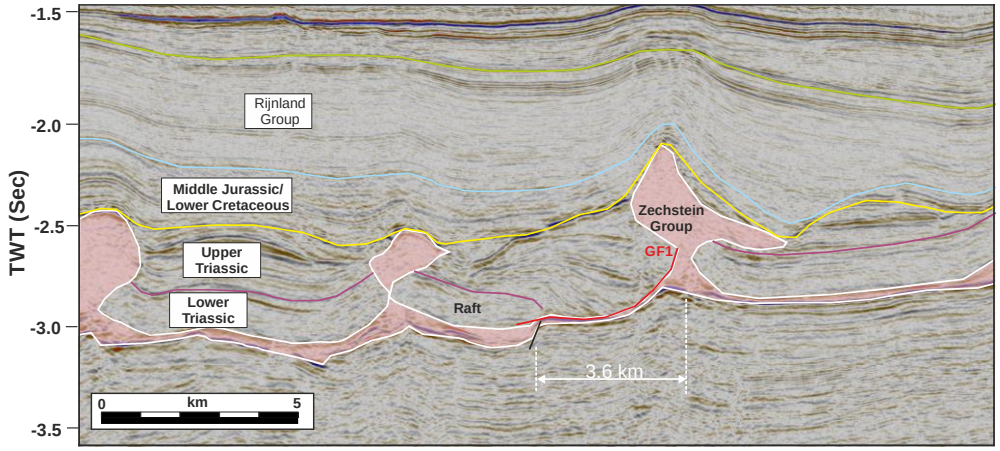
Potentially (higher/ sealed?) stringer density due to salt flow

TNO, 2017





CONSTRAINTS ON STRESSES AND PORE PRESSURE IN STRINGERS AROUND WELDS



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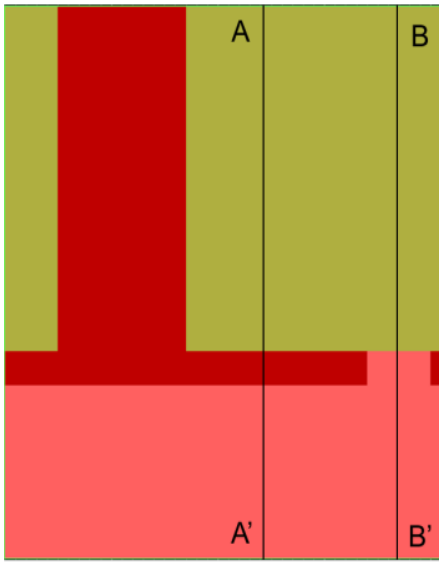
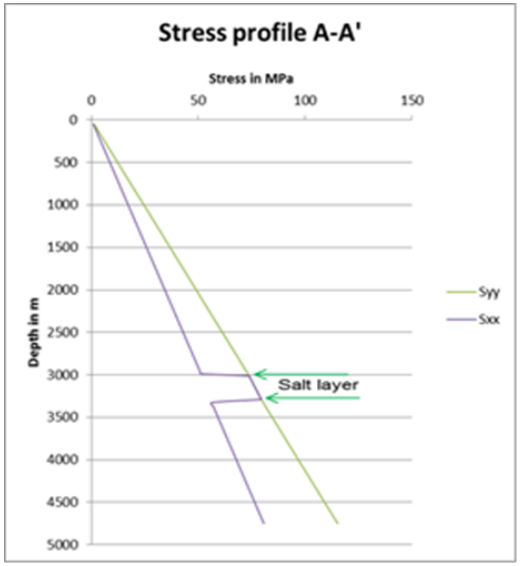
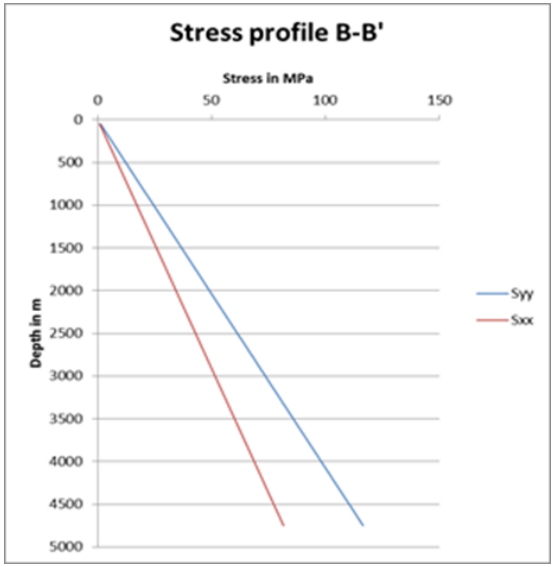


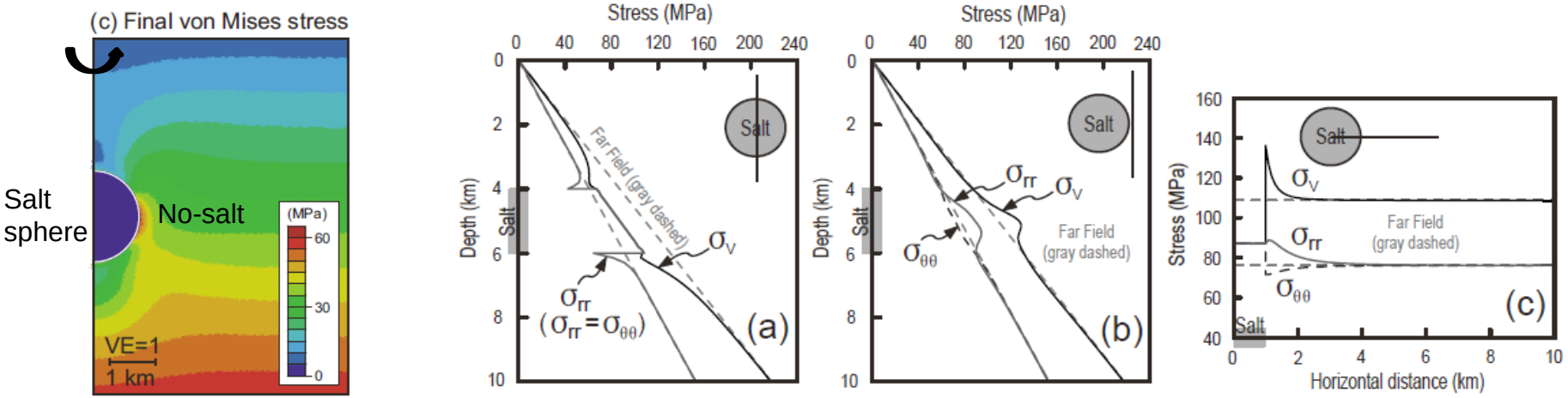




Grebe & Ter Heege (2013)

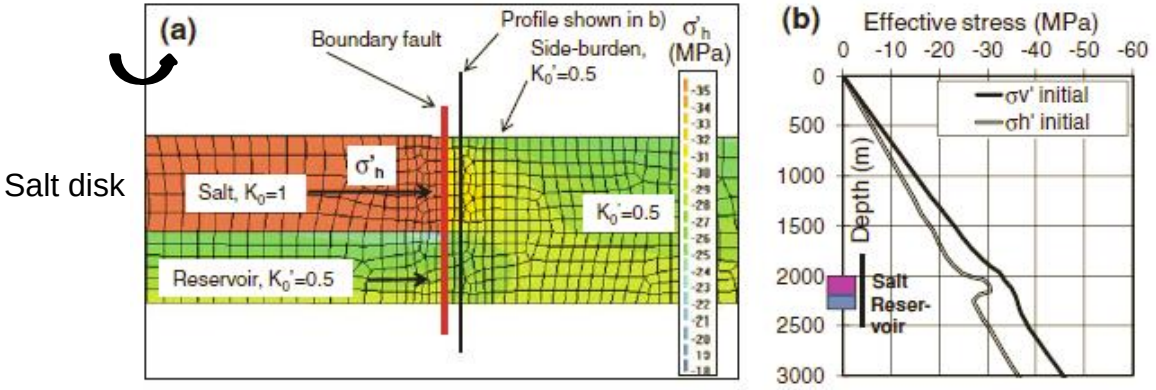
CONSTRAINTS ON STRESSES AND PORE PRESSURE AROUND SALT BODIES

- Stress in salt and stress perturbation in formations adjacent to salt bodies



(Luo et al. 2011)

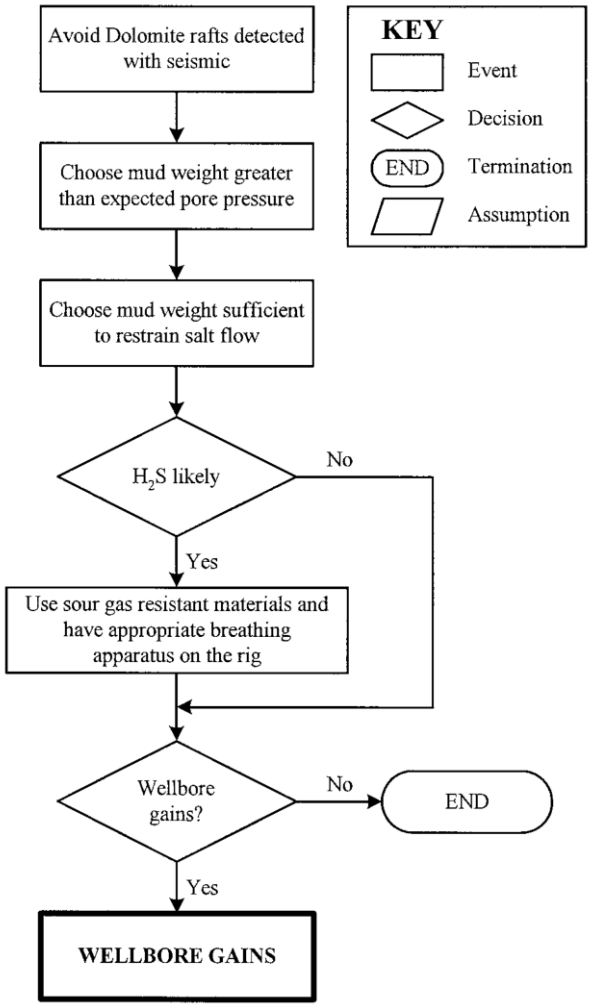
- Stress perturbation in formations adjacent to salt bodies

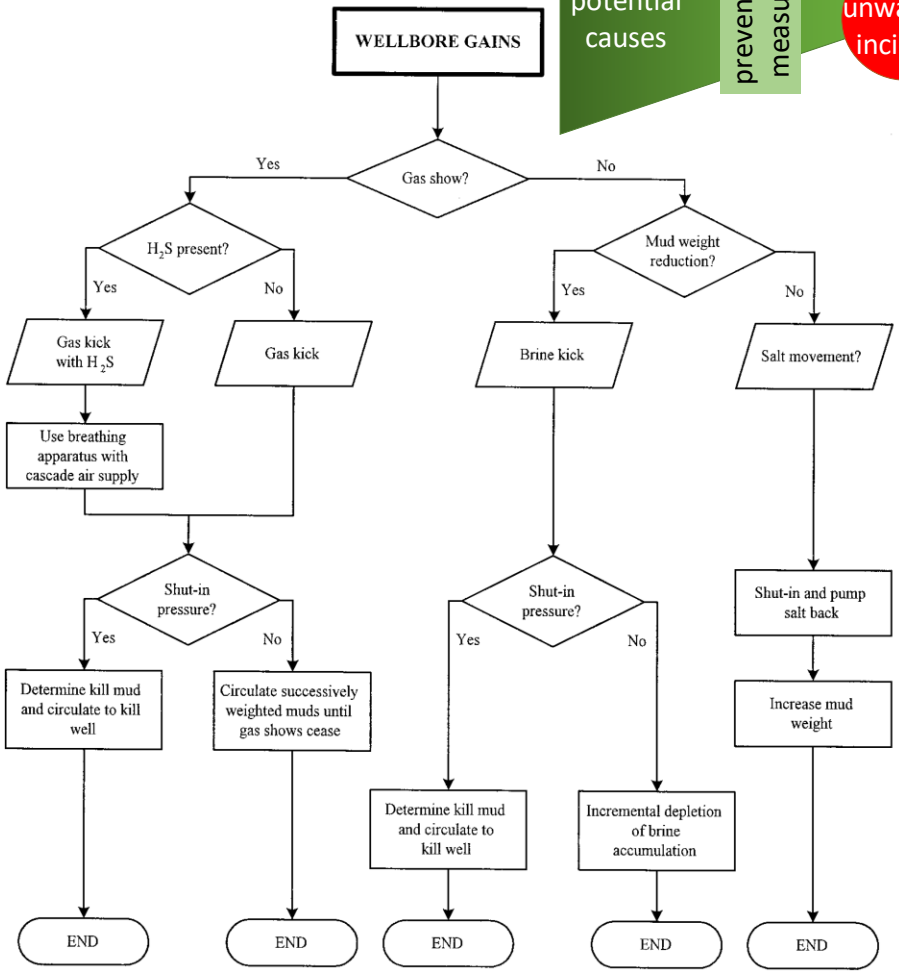


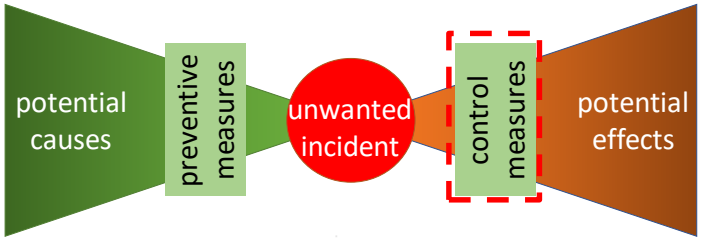
(Orlic & Wassing, 2012)

CONTROL MEASURES TO MITIGATE GAS & BRINE KICKS WHEN DRILLING STRINGERS

TNO innovation for life







Williamson et al. (1997)

DISCUSSION: WHERE IS THE MAIN ADDED VALUE FOR REDUCING RISKS?

TNO innovation for life

Mitigation measures for hazards when drilling salt formations:

- **Preventive measures**
  - Geological typing: Finding proxies/correlations between overpressures and geological parameters → *enough cases for statistics or correlations?* **(BREAKOUT SESSION 1)**
  - Constraints stringer pore pressures: Predictive models for burial history (P-T paths), compaction and fluid generation → *sufficient accuracy for practical use in preventing drilling hazards?* **(BREAKOUT SESSION 2)**
  - Imaging stringers: Improving seismic processing to detect stringers → *sufficient seismic resolution (new processing methods)?* **(BREAKOUT SESSION 3)**
- **Control measures while drilling (BREAKOUT SESSION 4)**
  - Incident handling: Standardized action protocols for handling stringers?
  - Drillers' recipes: Changing mud weights, conditions for shut-in?
- **Or some combination of the above…**