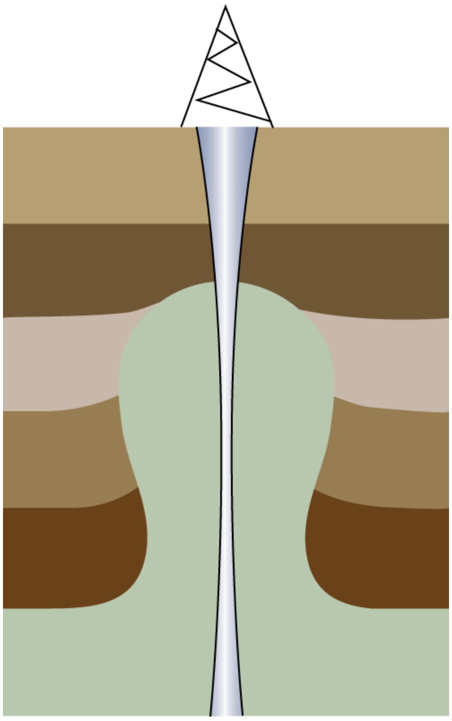
"Squeezing Salts" – an expensive problem

May 11, 2004
Utrecht

Proceedings

by Jaap Breunese & Barthold Schroot, TNO-NITG



Netherlands Institute of Applied Geoscience TNO
Princetonlaan 6
Utrecht , the Netherlands

Organised by TNO-NITG
and supported by EBN

“Squeezing Salts” – an expensive problem

May 11, 2004
Utrecht

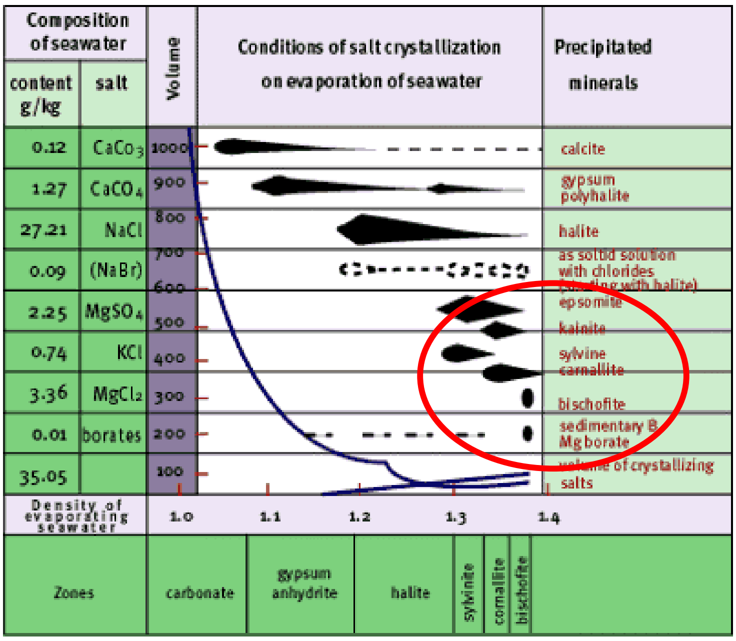
Introduction

On May 11th, 2004 a one-day seminar was organised in Utrecht by the Netherlands Institute of Applied Geoscience TNO (TNO-NITG) on the topic “Squeezing Salts” and aiming at providing a forum for discussion to relevant parties active in the Netherlands. These include the E&P operators, service industry, consultants, research institutes and university groups. The initiative was supported by EBN.

The K-or Mg-rich squeezing salts represent a challenge often encountered when drilling through the Zechstein Group. Over the last 40 odd years it has been found that these salts, with their specific properties and behaviour, have resulted in delays in drilling operations, adjusted casing schemes and even the loss of many wells. All of these consequences have a negative economic impact. Therefore, the "squeezing salts" can be considered to constitute an expensive problem to all.

The main objectives of the day were to exchange information and possibly reach consensus about questions such as:

- Do we agree on how to define squeezing salts?
- Can we predict where they occur?
- How do we deal with the problem in a practical manner?
- When are expensive changes to casing schemes (e.g. MUST casing) really required?



Successive precipitation of salts from seawater with reduction of its volume and densification by evaporation (after Valyashko in Strakhov, 1962).

(Carnallite = $KMgCl_3.6H_2O$)

(Bischofite = $MgCl_2.6H_2O$)

Scheme showing different evaporitic minerals and their positions in successive precipitation.

Squeezing Salts: Experience within Total E&P Nederland

Bertrand Bacaud
Total, E&P Nederland

30 years of drilling and production in the Dutch North Sea have provided Total E&P Nederland with a wide range of squeezing salt experiences, from collapse during drilling to collapse after more than 15 years of production. Over the years, a methodology based on experience has been developed to minimize the problems during drilling and completion. Deviation, inadequate mud chemistry and duration of exposure of the Zechstein to mud are aggravating factors. Subsidence linked to reservoir depletion may also play a role.

In one specific area, a severe squeezing salt interval has been eventually localized in the top part of the Zechstein, above a strong seismic marker linked to anhydrite deposits. A heavy drilling and completion program has been defined to cross it. It includes LTOBM, under reaming over nominal diameter and covering of the most problematic zone with two heavy duty casings. After 6 to 7 years of production, no restriction in the tubing has yet been observed.

However, in most areas, predictability of potential problems remains limited. Contrast within Zechstein seismic facies is used as indicator before drilling. High and noisy GR is an indication of risky zones during drilling. The program is adapted to the difficulties encountered in the neighboring wells. In any case, the minimum standard program includes LTOBM, LWD-GR and one heavy duty casing covering Zechstein areas with high GR values.
Experience of collapse after a long production period is too limited to draw conclusions.

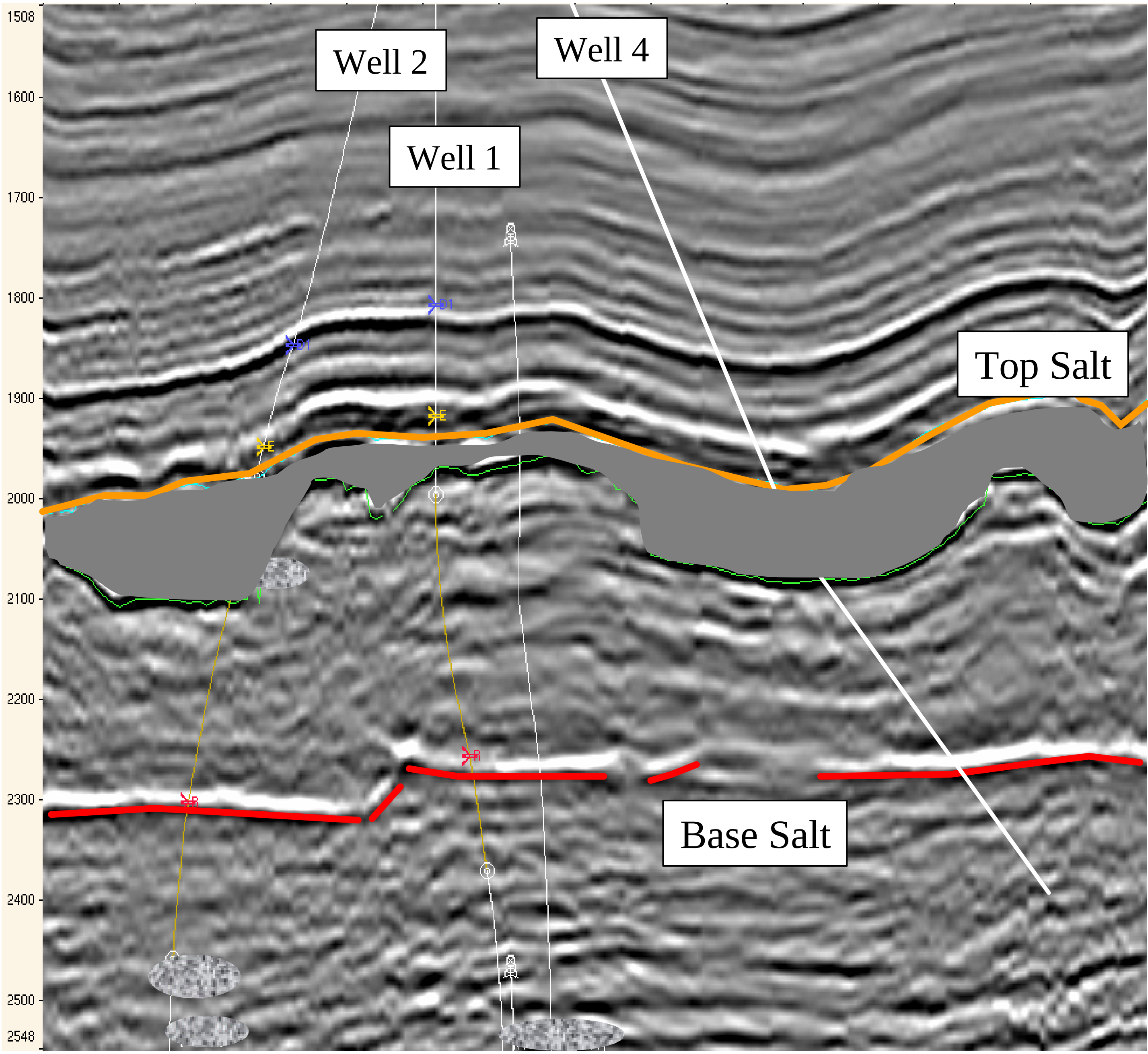
Programme

Focus on the K4 area

Another example

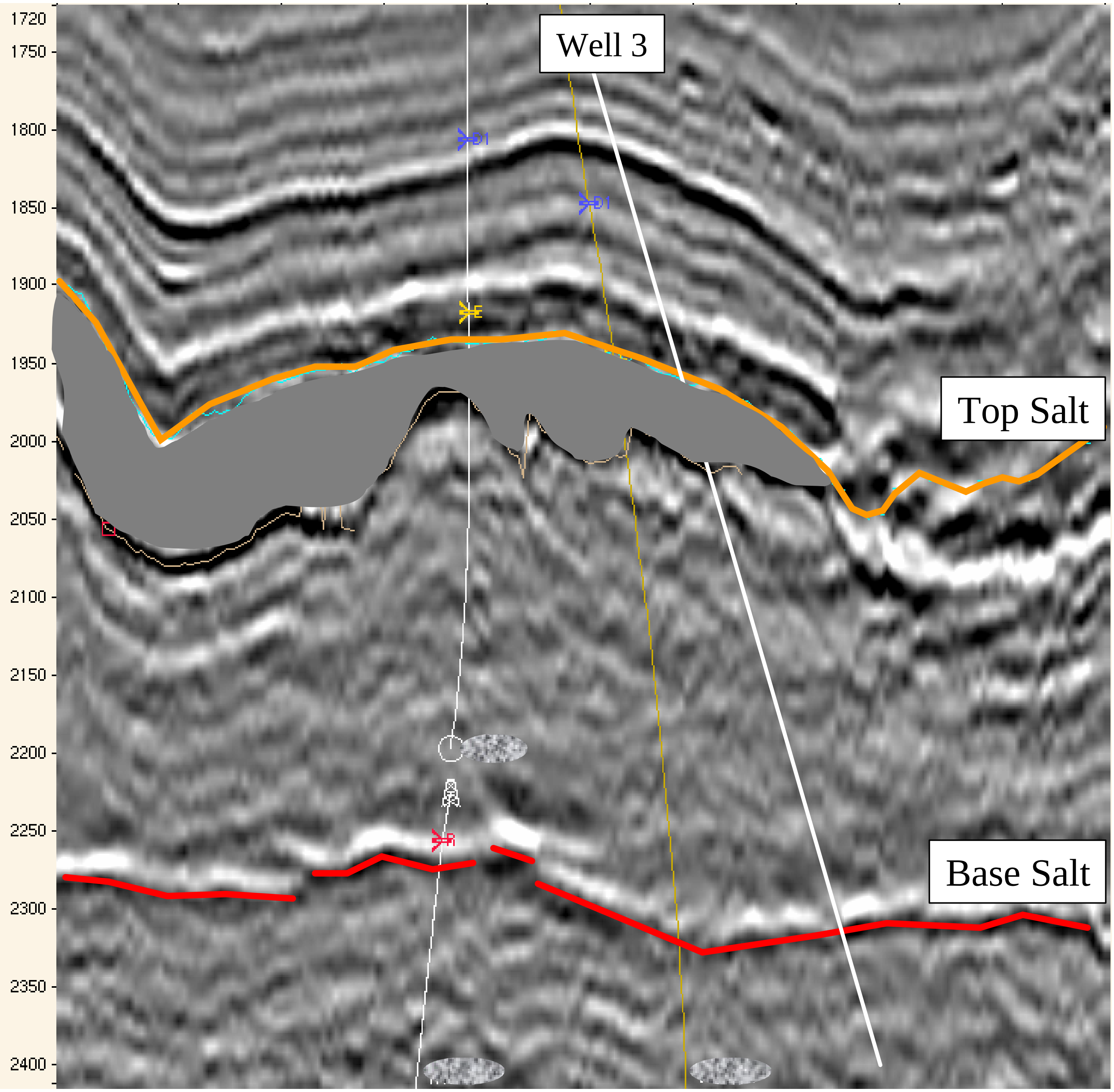
A long time later

K4 Area



Well 2
Well 4
Well 1
Top Salt
Base Salt
1508
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2548

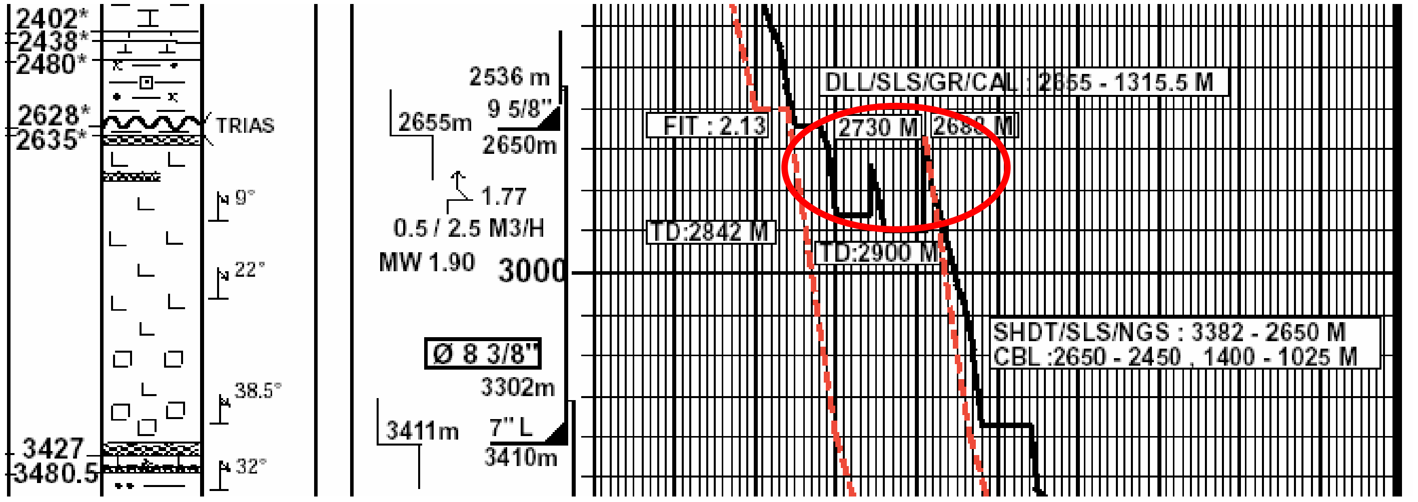
K4 Area



Well 3
Top Salt
Base Salt
1720
1750
1800
1850
1900
1950
2000
2050
2100
2150
2200
2250
2300
2350
2400

Well 1 (1997)

KCl Polymer mud used



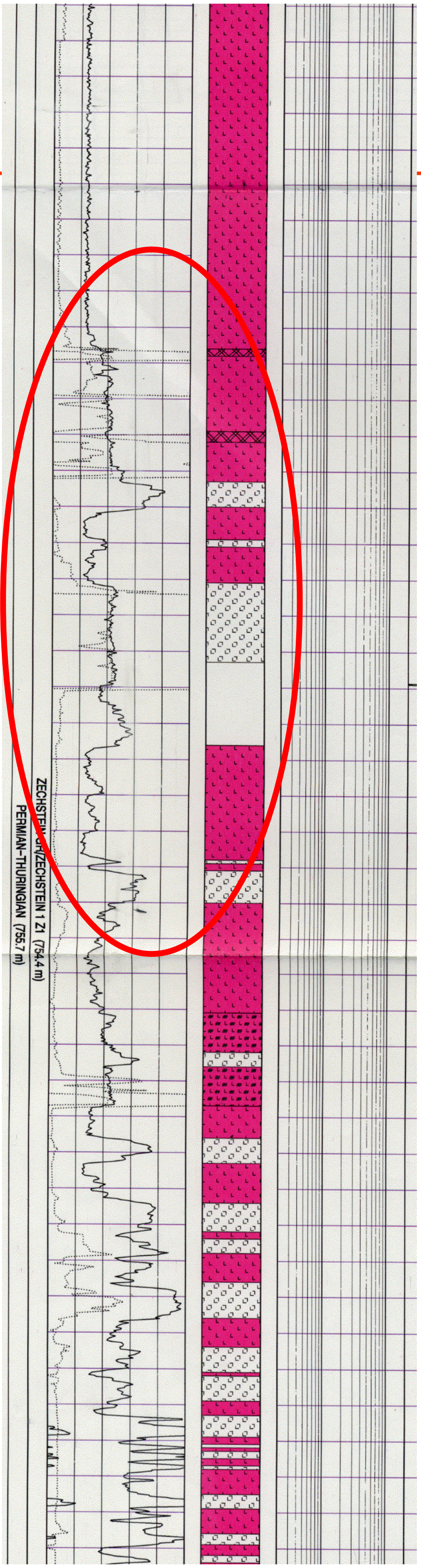
MW=1.32 → **BHA stuck @ 2842 m** → **MW=1.64** → **Side-Track**

BHA stuck @ 2899 m → **Gain 2.5 m3/h** → **MW=1.77** → **Side-Track**

MW=1.90 → **Drill to TD**

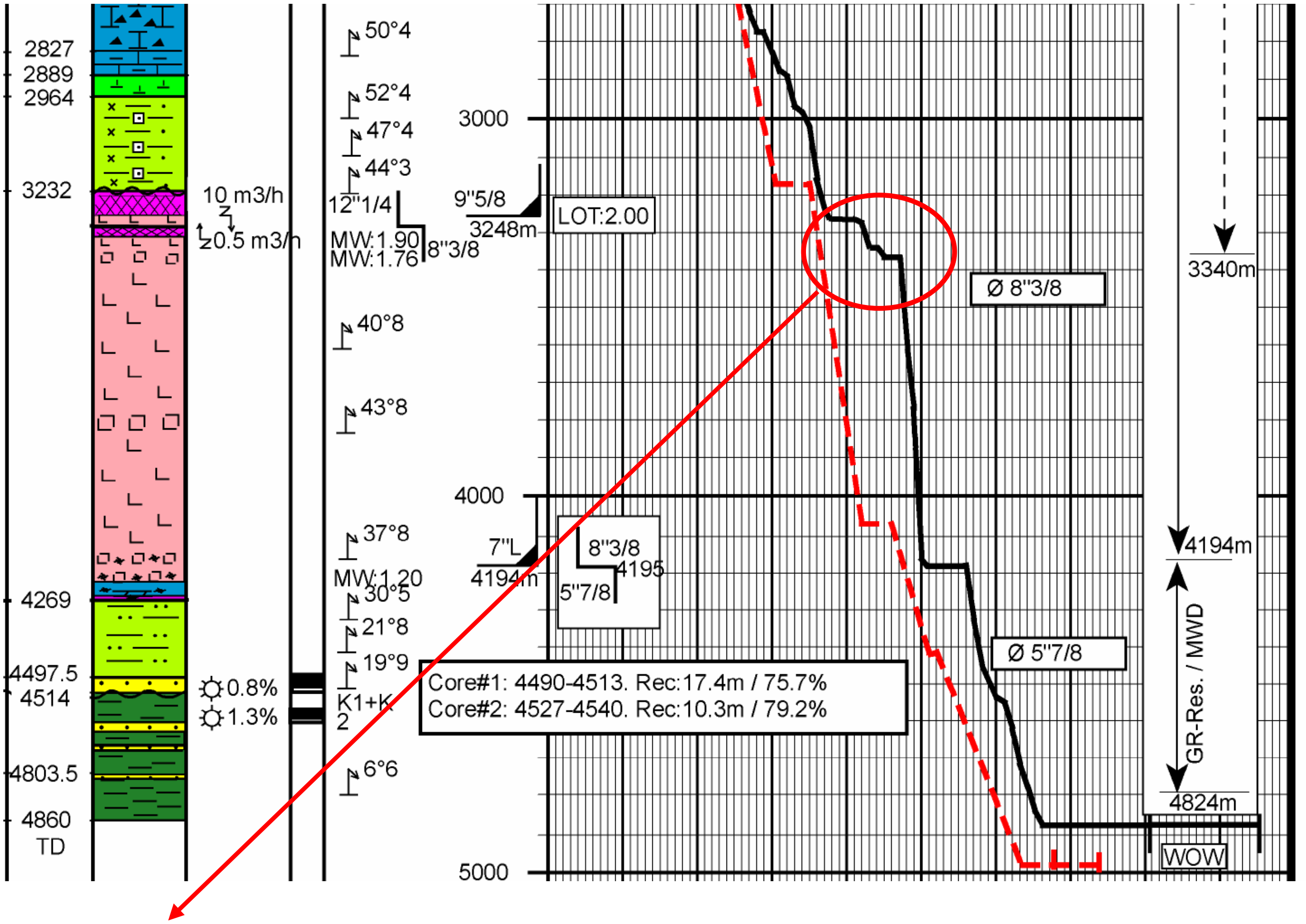
@ 2900 m : Carnalite + Halite + tr. of Kieserite on sample

Well 1



Well 2 (1997)

Salt saturated mud used



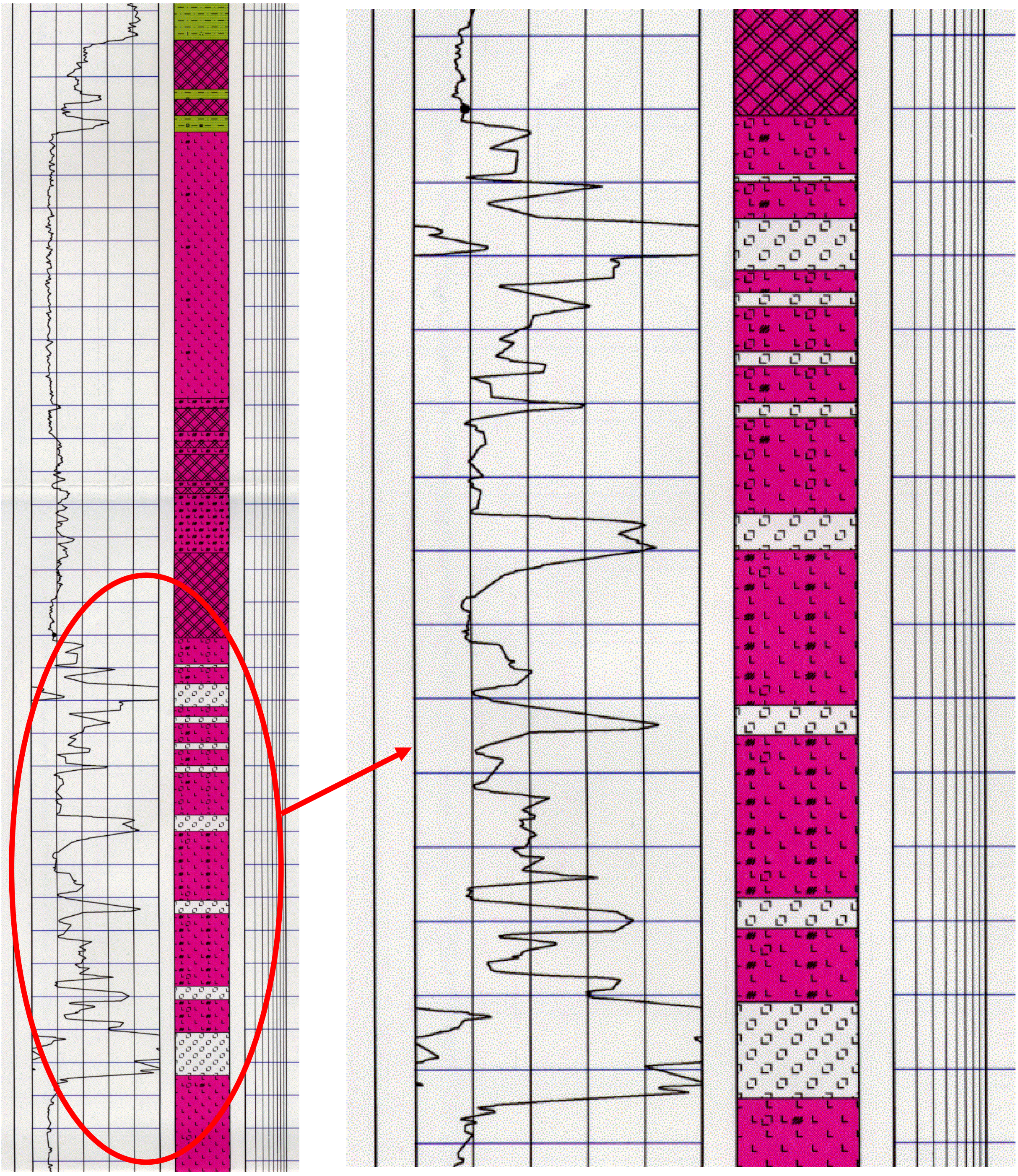
MW=1.65 → Gain (450 l in 10') → MW=1.90 → Losses (10 m3/h) →

LCM+MW=1.77 → Losses → LCM+MW=1.74 → Gain (450 l in 10') →

Cement Plug → Drill to TD → Gain (4 m3) during Wiper trip →

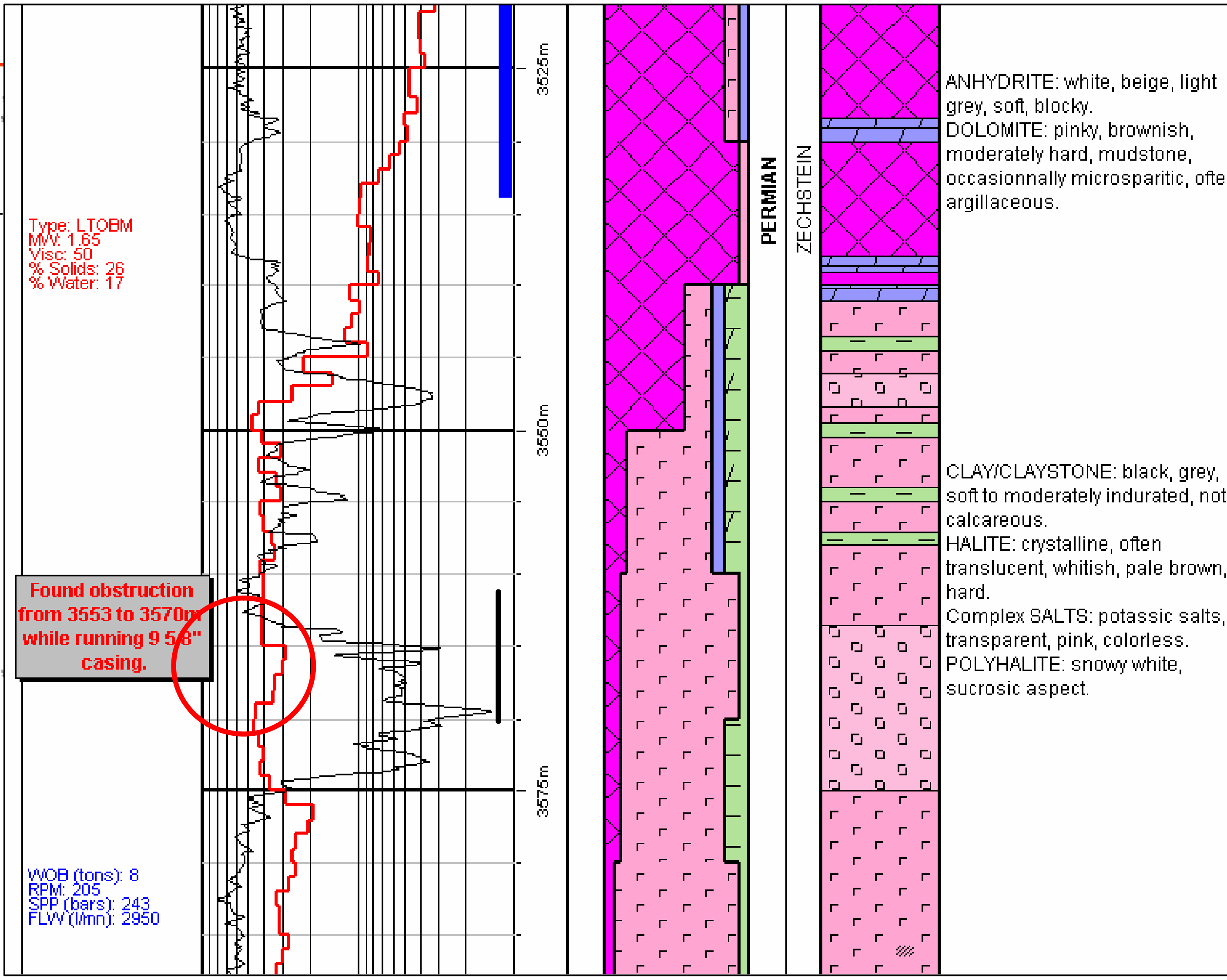
MW=1.78 → Run heavy wall 7" liner → Collapse 20 days later

Well 2



Well 3 (2001)

OBM used

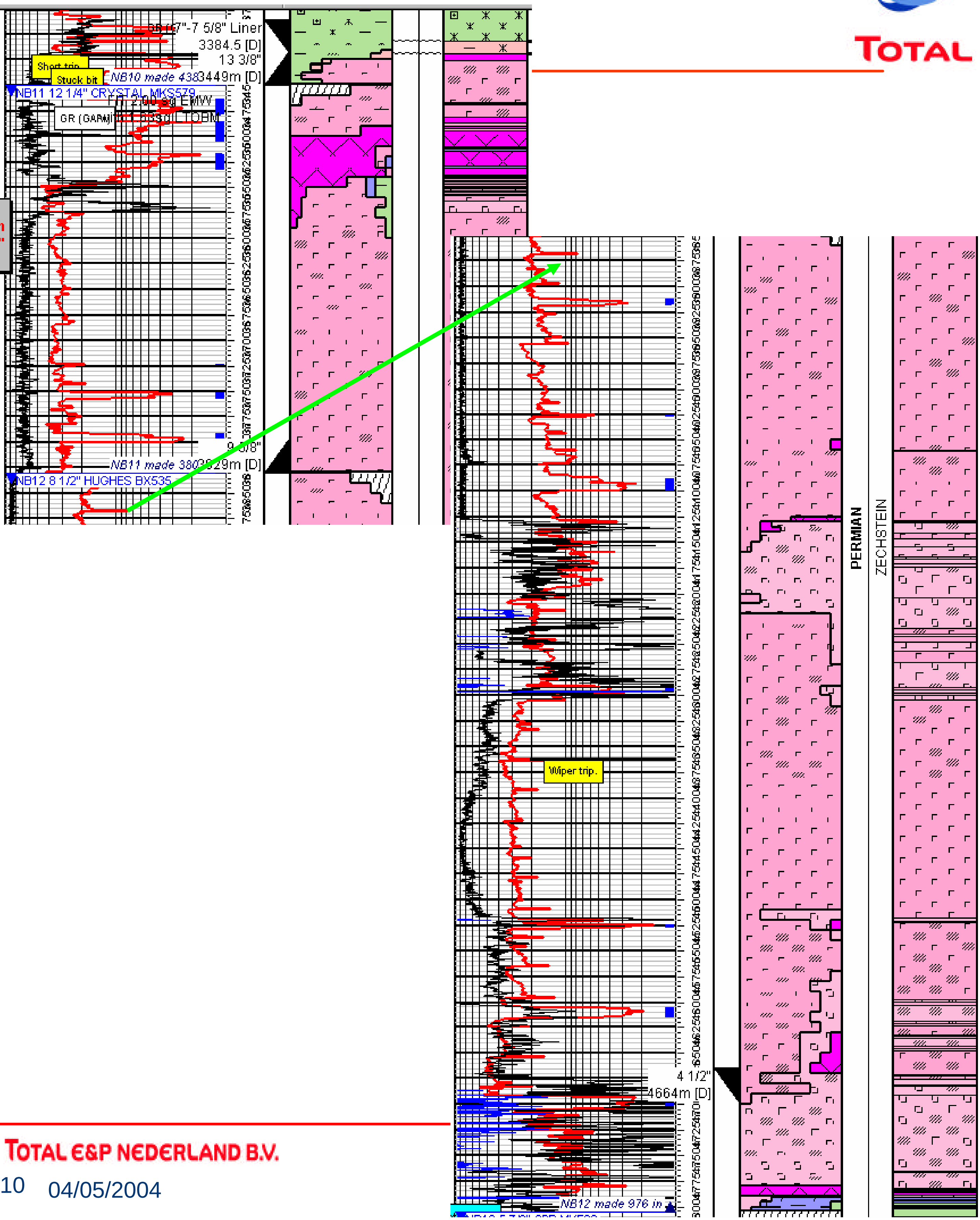


Drilled to 12 1/4" TD w/ OBM 1.63 → **Run 9 5/8"-10 3/4" csg**

→ **Obstr. @ 3561 m** → **Drilled obstr. F/t 3562-3570 m w/ 8 1/2" bit & 12 1/4" hole open.**

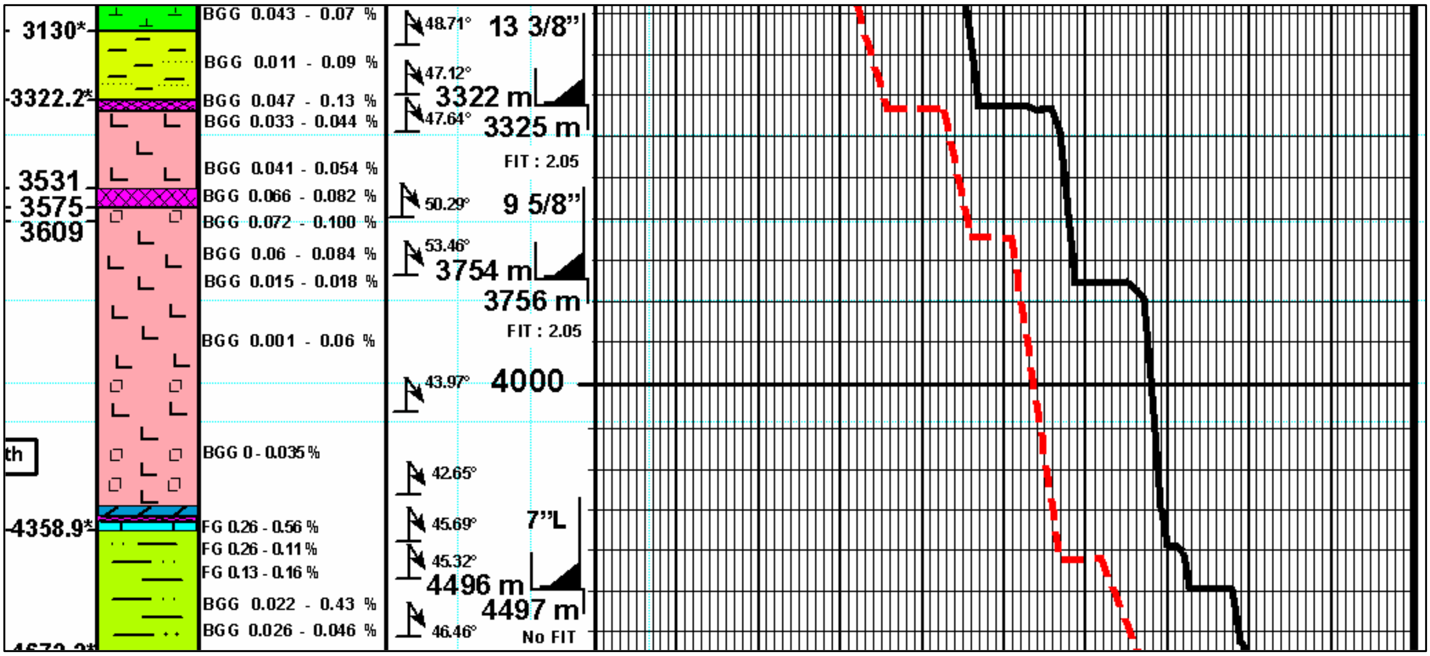
MW=1.75 → **Ream w/ T. spots** → **MW=1.81** → **Run csg**

Well 3


7"-7 5/8" Liner
3384.5 [D]
13 3/8"
Short trip
Stuck bit
NB10 made 438
3449m [D]
NB11 12 1/4" CRYSTAL MKS579
9 5/8"
NB11 made 380
29m [D]
NB12 8 1/2" HUGHES BX535
Wiper trip.
4 1/2"
4664m [D]
NB12 made 976 in
PERMIAN
ZECHSTEIN

Well 4 (2003)

OBM used



Drilled to 12 1/4” TD w/ OBM 1.75 & w/ 14” under-reamer

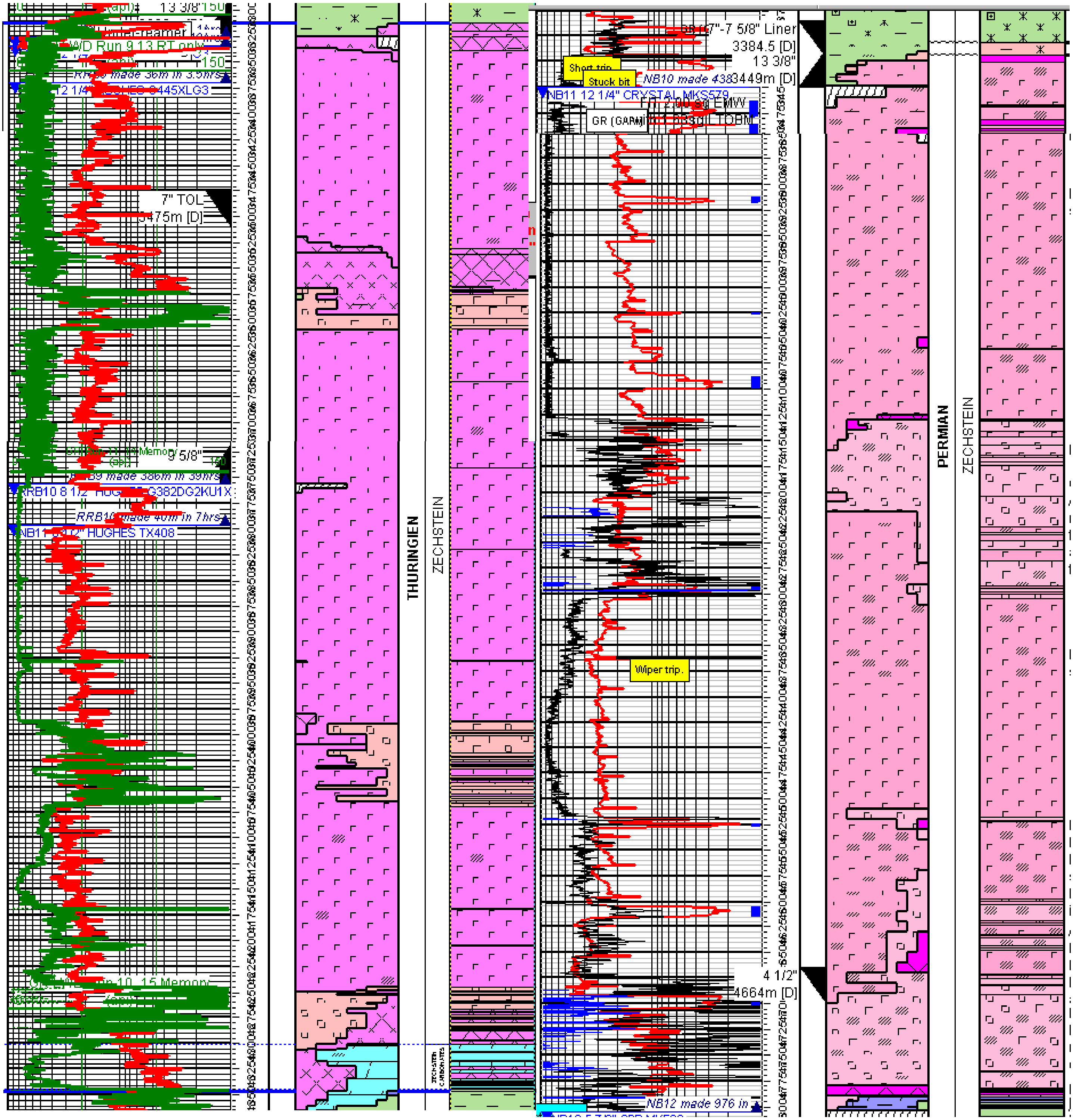
Run 9 5/8” csg + 10 3/4” must

Drilled to 8 1/2” TD w/ OBM 1.65 & w/ 9 1/2” under-reamer & Rotary steerable assembly

Run 7” liner

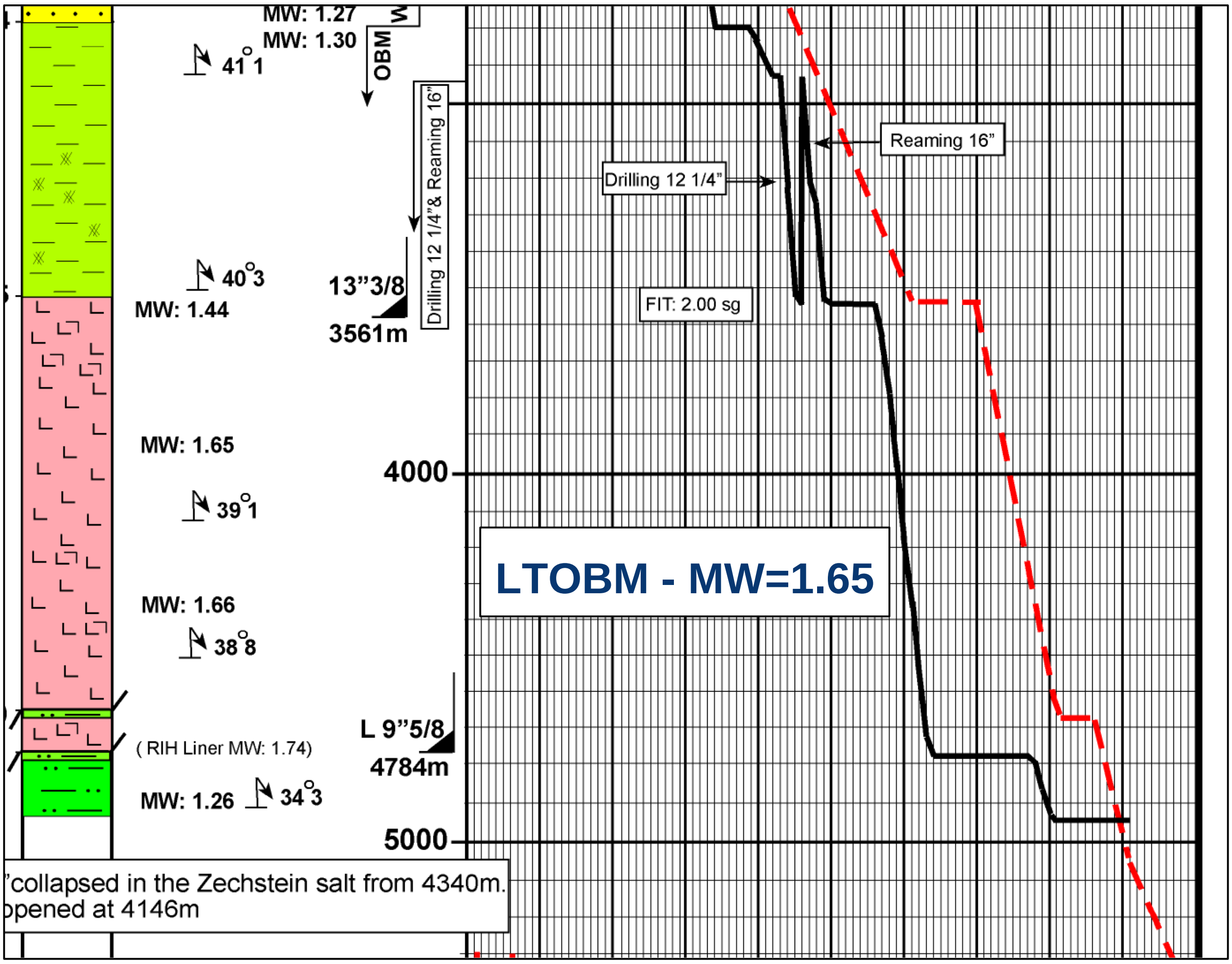
Well 4

Well 3



13 3/8"
7" TOL
3475m [D]
9 5/8"
RRB10 8 1/2" HUGHES
NB11 8 1/2" HUGHES TX408
7"-7 5/8" Liner
3384.5 [D]
13 3/8"
3449m [D]
Short trip
Stuck bit
NB11 12 1/4" CRYSTAL MKS579
GR (GAPI)
Wiper trip.
4 1/2"
4664m [D]
NB12 made 976 in
THURINGIEN
ZECHSTEIN
PERMIAN
ZECHSTEIN

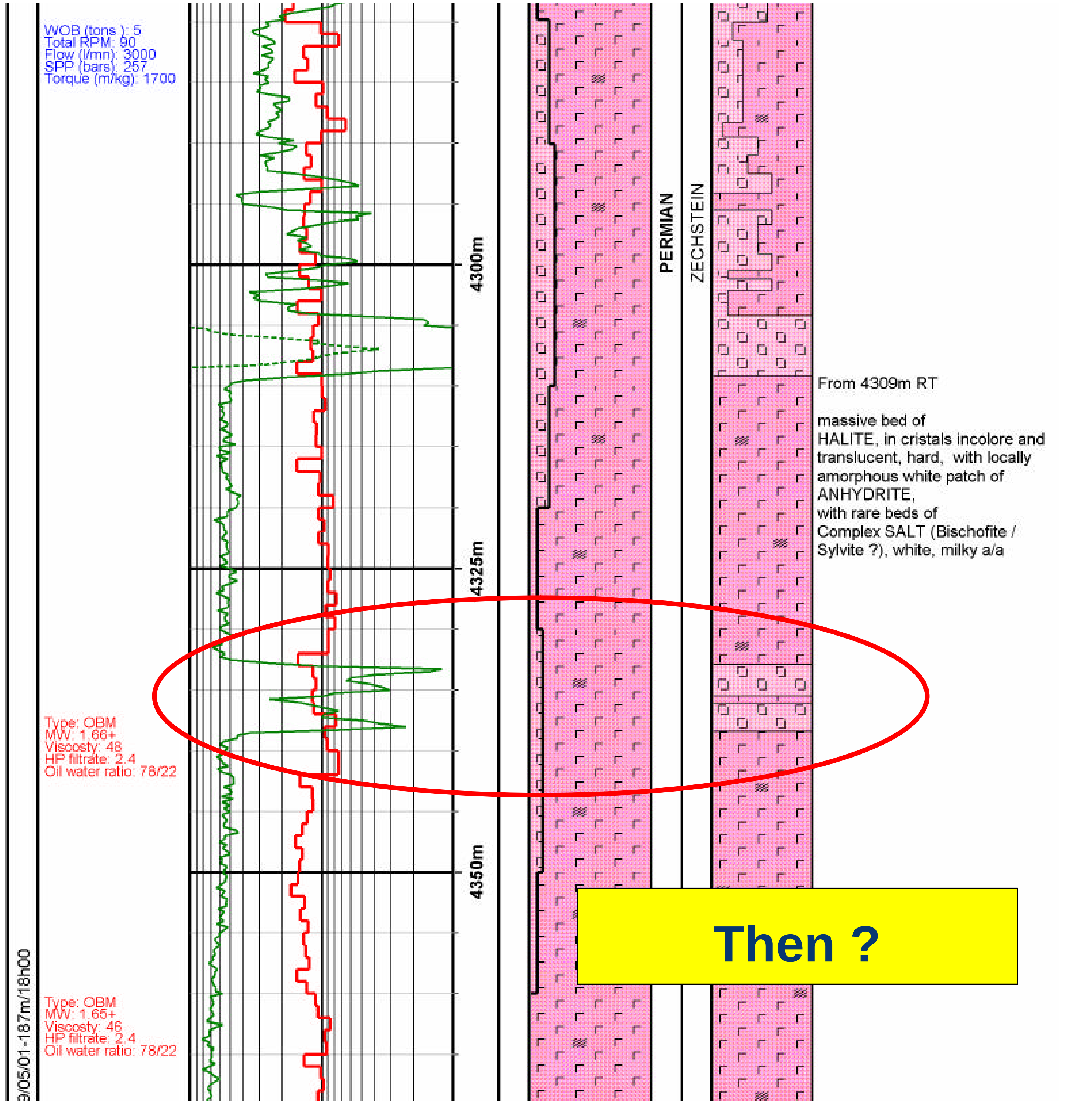
Well 5 (exploration)



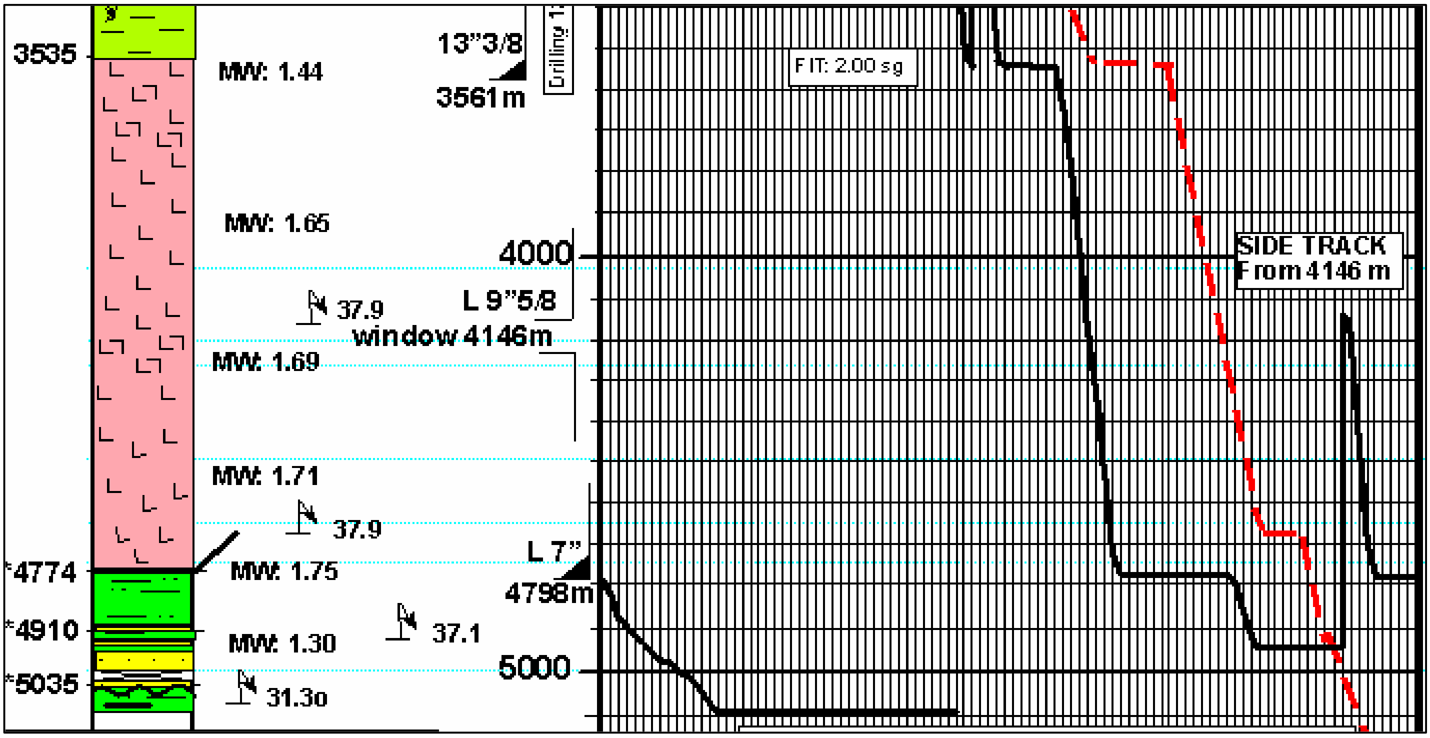
Drill to TD → Wiper Trip w/o tight spot → MW = 1.68 → Wiper Trip w tight spot → MW = 1.74 → Run liner + Tie back → Drill 8 1/2" to 4932 m → Wiper Trip

Unable to POOH above 4755 m | **Unable to go down to 4340 m**

Well 5 (exploration)



Well 5 sidetrack

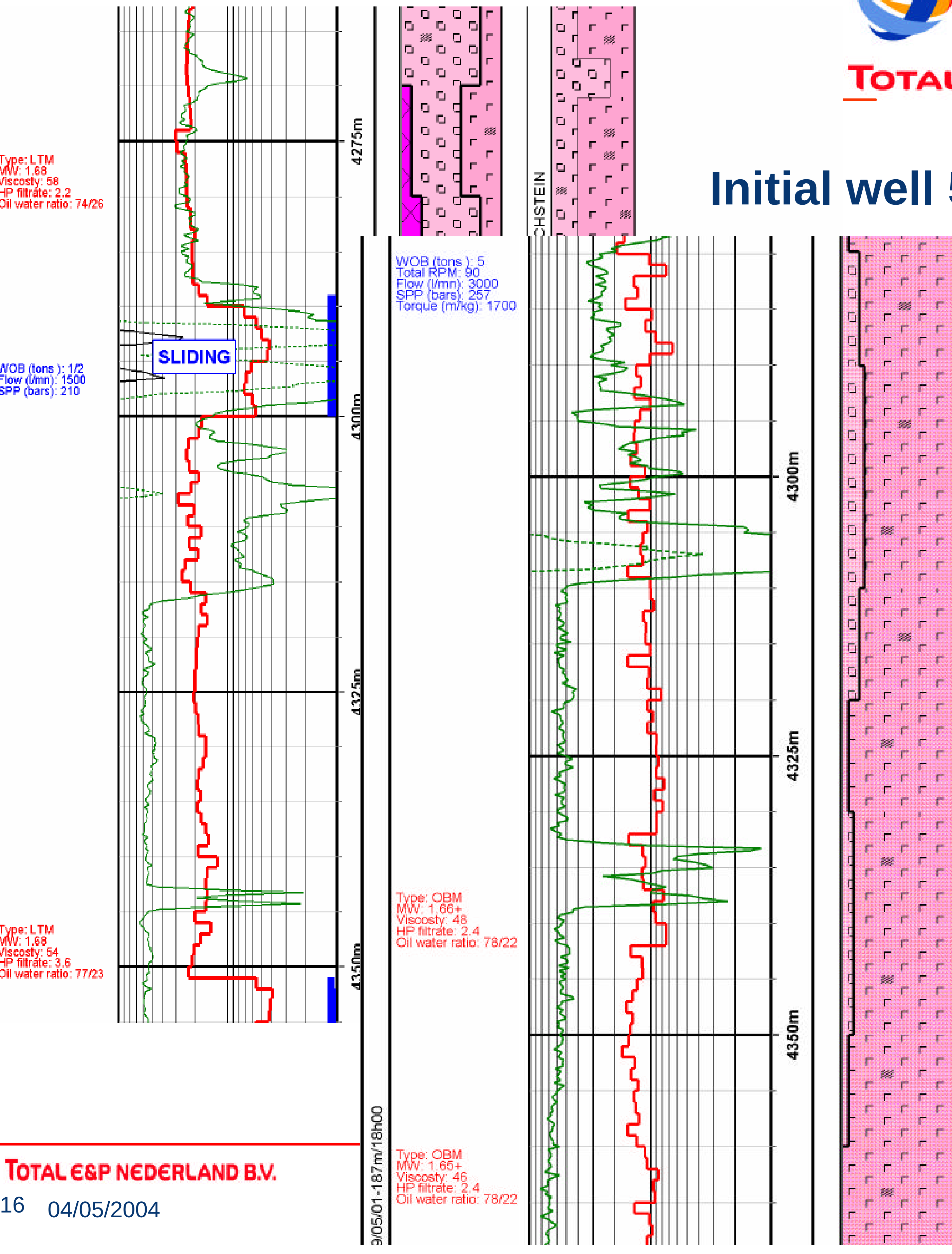


Side-Track 8 1/2" w/ OBM 1.74 sg

Run 7" X 7 5/8" Liner

Well 5 Sidetrack

Initial well 5



A long time later

Well 6

Drilled in 1984/85

Put into production <u>**18 years later**</u>

Collapsed in 2002

Well 7

Drilled in 1973

Completed in 1977 <u>**14 years later**</u>

Collapsed in 1987

Zechstein well engineering: A Groningen case study

Pierre Kriesels
Nederlandse Aardolie Maatschappij, P.O. Box 28000, 9400 HH Assen, the Netherlands

In the past, a certain number of Groningen production wells were lost due to casing collapse (or other mechanical reasons) caused by the so-call squeezing salt.

In order to assess the risks of squeezing salt for the Groningen wells, a study has been initiated during the Groningen Field Review (project B2), which is aiming to screen through previous NAM failures related to squeezing salt, to develop some prediction means and to have a ranking list of the Groningen clusters with regards to the risk of squeezing salt activities.

The main results are:

- The drilling data (completion date vs date of failure), suggest that most of the casing collapses due to the squeezing salt has occurred between 1960 and 1980 during a high level of drilling activity period, and in a time frame between 1 month to 3 years after the completion date.
- A geological model has been built which suggests the area of absence of squeezing salt located either at the highs of the Zechstein paleography (eroded by Base Lower Cretaceous Unconformity) or at the lows of the Zechstein paleography (compaction effect due to thick Triassic package).
- A map of "none squeezing salt prone" area (squeezing salt likely to be absent) has been derived for the Groningen field from the geological model and the existing seismic data (time migrated).
- A ranking list of the Groningen clusters has been established with (H) High, (M) Medium and (L) Low risk to overcome squeezing salt activities.

Zechstein Well Engineering:
A Groningen Case Study

David Vannaxay
Presenter: Pierre Kriesels

Talk outline

? Problem statement
? Data Analysis
? Geological model
? Casing design
? Operational considerations
? Conclusions

Problem statement

? In the past, several Groningen production wells collapsed due to squeezing salt.

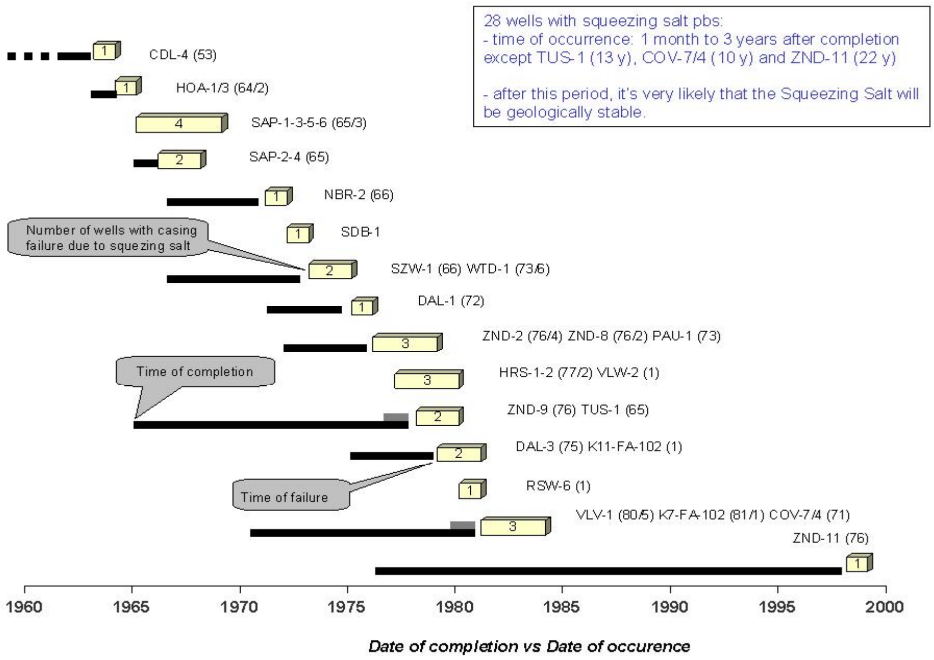
? Cost of repair/replacement is substantial.

? Effect on environment and reputation is minor.

? Probability of failure is (was) medium

Data Analysis

(North East Netherlands)



Data Analysis

? Most collapses occurred between 1960 and 1980, during a high level of drilling activity.

? Time between completion and collapse typically between 1 month and 3 years, with exceptions.

? Independent of well inclination (between 0 ? 40 degrees).

Geological model

? Objective:

? To estimate the probability of squeezing salt.

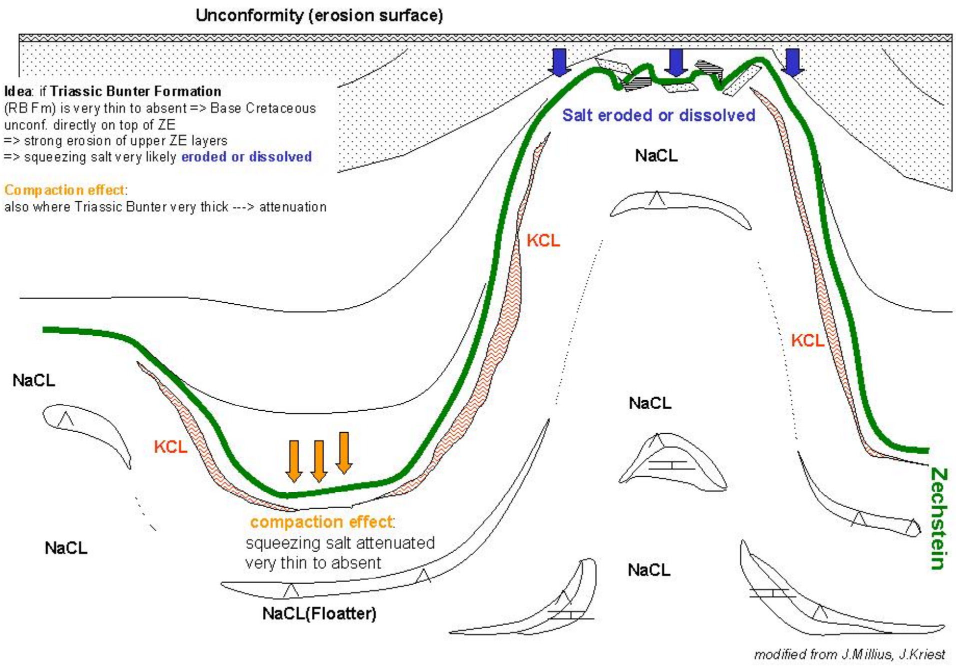
? To possibly change well trajectory

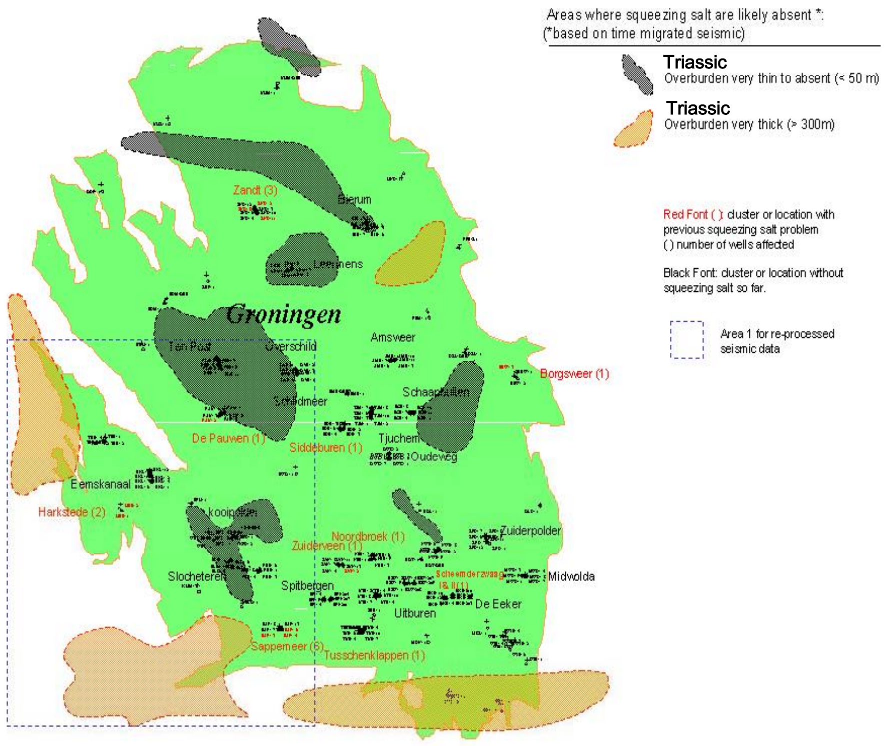
? Based on geological modelling

? To tune the well design to the probability of occurrence

? To be operationally prepared when drilling the section

Simple Geological model





Casing design

? Drill the well and Design the casing such that it can withstand the squeezing salt.

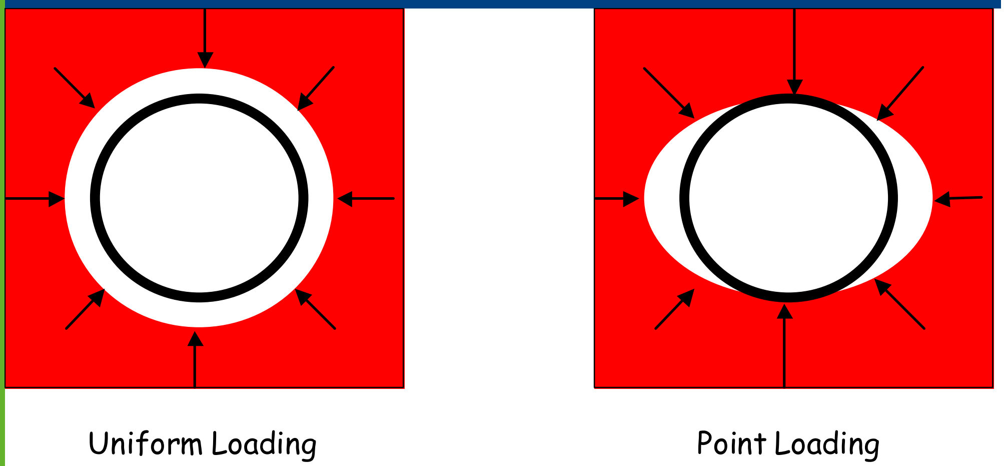
? To consider:

- ? Mud type/density
- ? Internal pressure
- ? External salt “pressure”
- ? Point loading

Casing design

Point loading, what is meant (for this discussion)

?



Casing design

Point loading

? Why is it considered:

- ? Casing collapse that can not be explained by uniform salt loading

? How does it happen:

- ? Non uniform cement sheet
- ? Washed out, irregular hole
- ? Non uniform Tectonic stresses
- ? ??

Casing design

Point loading, what can be done

? Prevent point loading

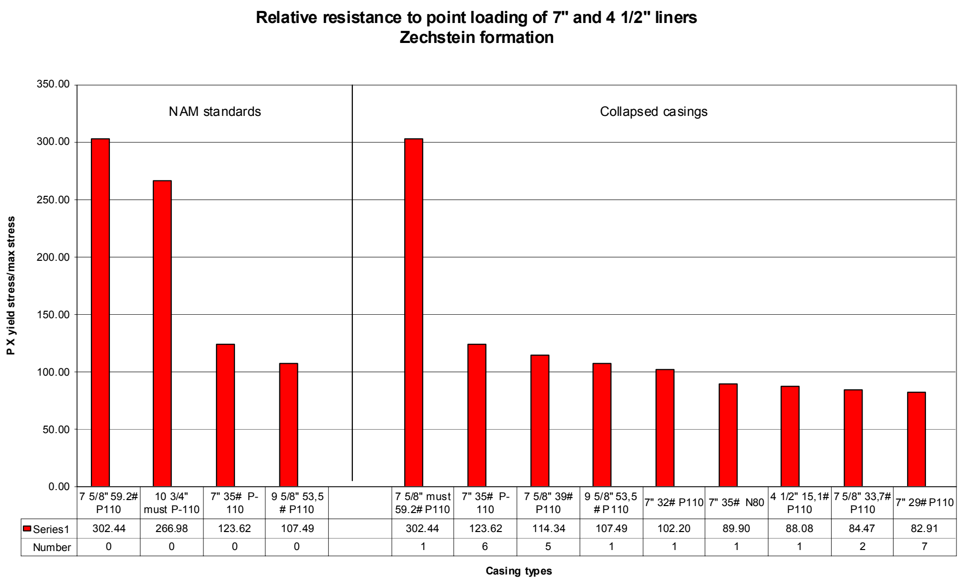
- ? Annulus fully filled with cement
- ? Prevent wash-out <-> irregular hole shape
  - ? Salt saturated mud
  - ? Oil Based Mud

? Design casing to withstand point loading

- ? Double casing string with cement in between and in annulus
  - ? Common practice in some regions (US)
  - ? Hard to model/predict final strength
- ? Heavy wall pipe: MUST casing

Casing design

(Resistance to point loading)



Operational considerations

- ? Problem:
  - ? The Squeezing salt “grabs” the BHA while drilling
- ? Preventive measures:
  - ? High mud weight
  - ? Water based mud > Wash-out
  - ? Water pills
  - ? Jar Placement
  - ? Back reamers
  - ? Drilling practice/Awareness
  - ? ..

Conclusions

? A geological model can be used to quantify the probability of squeezing salts

? Proper Casing design and Operational practices can increase the resistance to collapse.

? Hence probability of squeezing salts can be decreased/quantified and and resistance to collapse tuned.

? This combination has led to a dramatic decrease of casing collapse problems.

Examples from Gaz de France

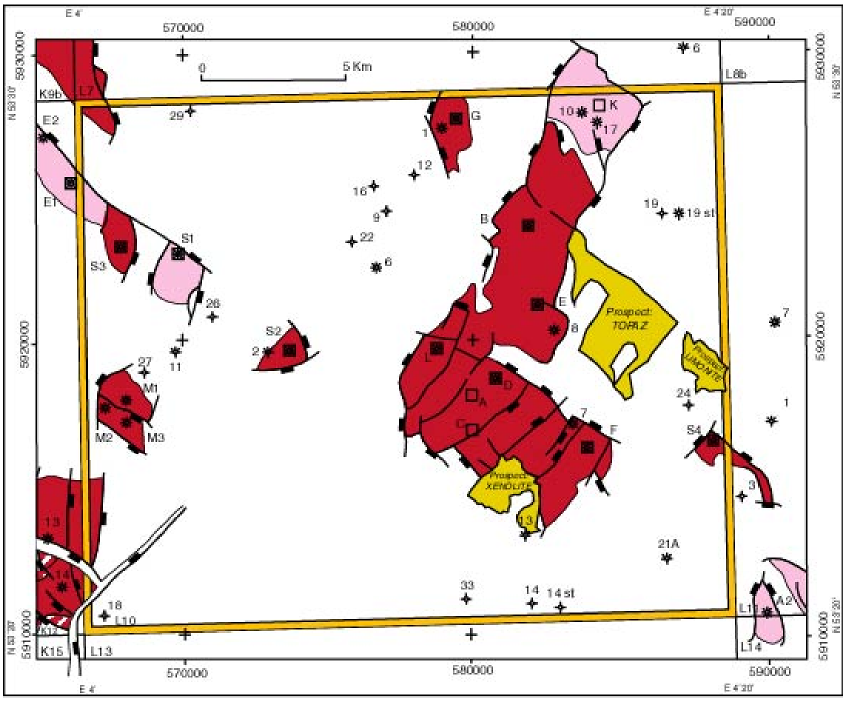
Hilbrand Graven
Gaz de France Production Nederland B.V.

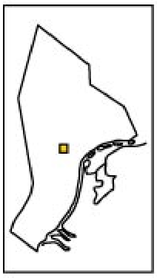
GDF Production Nederland B.V. is active in the Dutch K&L blocks as of the late sixties and drilled 150 wells through the Zechstein salt section to the Rotliegend reservoir. Problems with squeezing salts were experienced in several wells resulting in the loss of 6 wells. The lost wells had either 9 5/8" or 7" casing over the Zechstein section. Four of the six wells were lost in the early eighties and made GDF decide to run heavy wall casing over the mobile sections of the Zechstein salt, and optimize the drilling mud to stabilize the mobile salts as much as possible. The mobile sections were detected based on a combination of GR, sonic and caliper data. Examples of L10-K1A (lost after 9 5/8" and 5" collapse) and L10-M2 (10 ¾" casing) are presented and an example of log response of the mobile salts.

None of the wells with heavy wall casing were lost so far. The fact that none of the wells with heavy wall casing were lost, combined with the relatively low extra cost of approximately 100 to 150 Euro per meter, justifies using heavy wall pipe over intervals with mobile salts and over intervals were mobile salts are not proven but suspected to be present.

GDF operated wells drilled in or through Zechstein salt

Exploration wells:	**52**
Re-entries / production wells:	**100**
Wells lost due to salt movement:	**6**





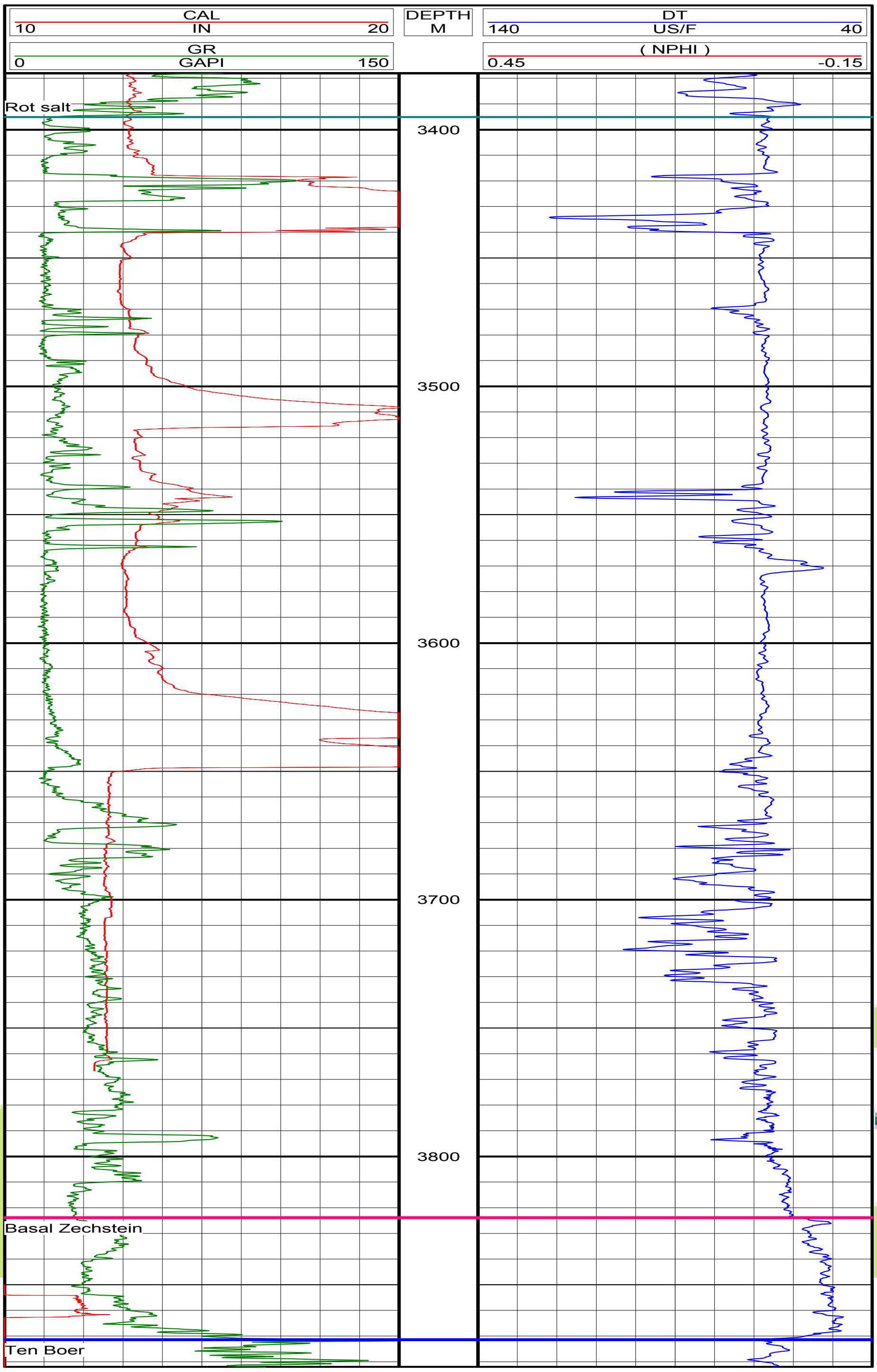
Gaz de France

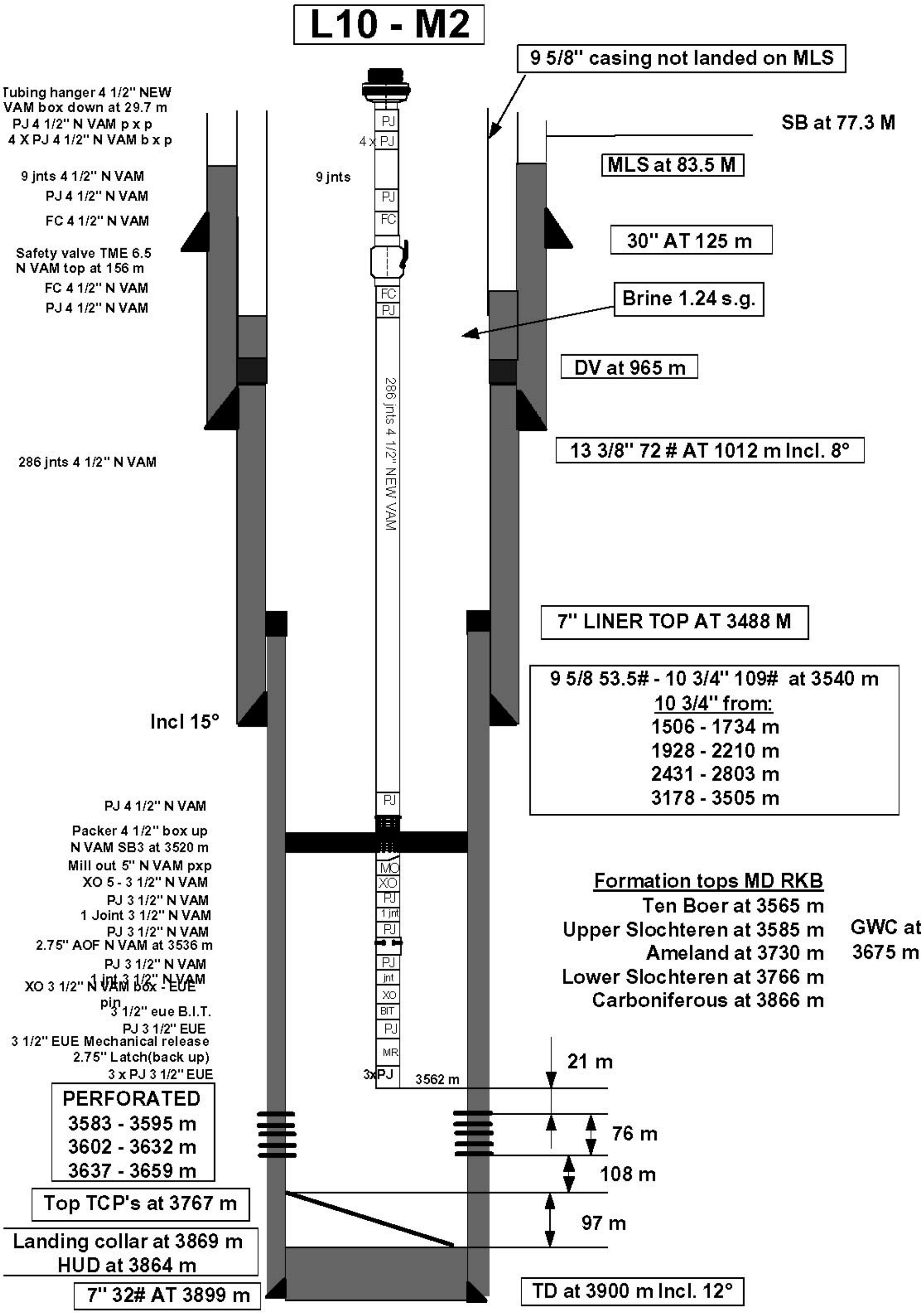
NETHERLANDS OFFSHORE

BLOCK L10

January, 2004

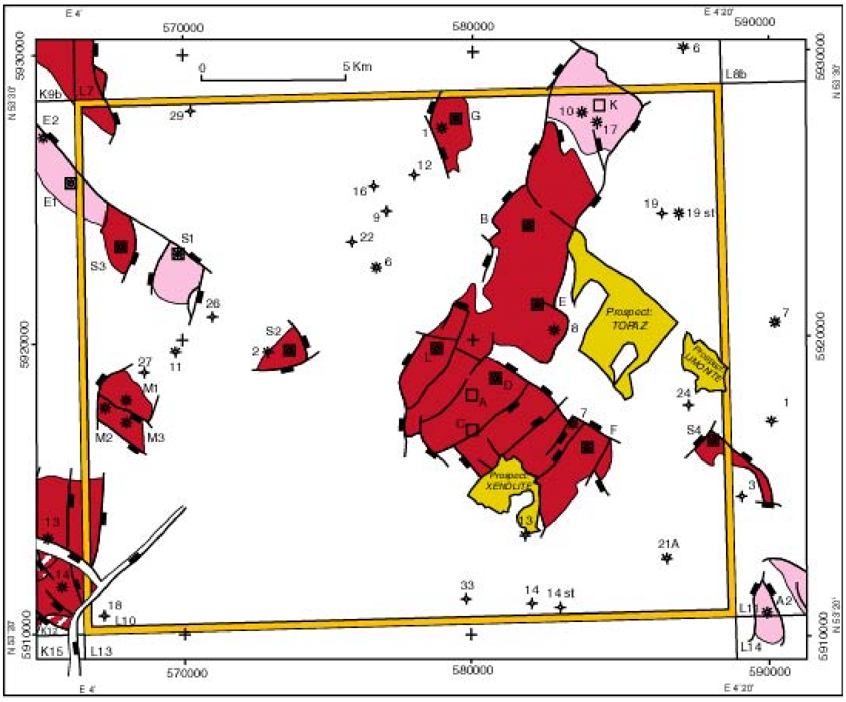
L10-M3 GR/CALIPER/DT

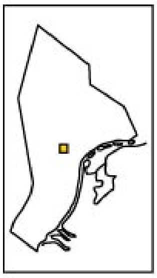



L10 - M2
9 5/8" casing not landed on MLS
Tubing hanger 4 1/2" NEW VAM box down at 29.7 m
PJ 4 1/2" N VAM p x p
4 X PJ 4 1/2" N VAM b x p
SB at 77.3 M
MLS at 83.5 M
9 jnts 4 1/2" N VAM
9 jnts
PJ 4 1/2" N VAM
FC 4 1/2" N VAM
30" AT 125 m
Safety valve TME 6.5 N VAM top at 156 m
Brine 1.24 s.g.
FC 4 1/2" N VAM
PJ 4 1/2" N VAM
DV at 965 m
286 jnts 4 1/2" NEW VAM
13 3/8" 72 # AT 1012 m Incl. 8°
286 jnts 4 1/2" N VAM
7" LINER TOP AT 3488 M
9 5/8 53.5# - 10 3/4" 109# at 3540 m
10 3/4" from:
1506 - 1734 m
1928 - 2210 m
2431 - 2803 m
3178 - 3505 m
Incl 15°
PJ 4 1/2" N VAM
Packer 4 1/2" box up N VAM SB3 at 3520 m
Mill out 5" N VAM pxp
XO 5 - 3 1/2" N VAM
PJ 3 1/2" N VAM
1 Joint 3 1/2" N VAM
PJ 3 1/2" N VAM
2.75" AOF N VAM at 3536 m
PJ 3 1/2" N VAM
1 jnt 3 1/2" N VAM
XO 3 1/2" N VAM box - EUE pin
3 1/2" eue B.I.T.
PJ 3 1/2" EUE
3 1/2" EUE Mechanical release
2.75" Latch(back up)
3 x PJ 3 1/2" EUE
Formation tops MD RKB
Ten Boer at 3565 m
Upper Slochteren at 3585 m
Ameland at 3730 m
Lower Slochteren at 3766 m
Carboniferous at 3866 m
GWC at 3675 m
3562 m
21 m
76 m
108 m
97 m
PERFORATED
3583 - 3595 m
3602 - 3632 m
3637 - 3659 m
Top TCP's at 3767 m
Landing collar at 3869 m
HUD at 3864 m
7" 32# AT 3899 m
TD at 3900 m Incl. 12°

Collapse pressures

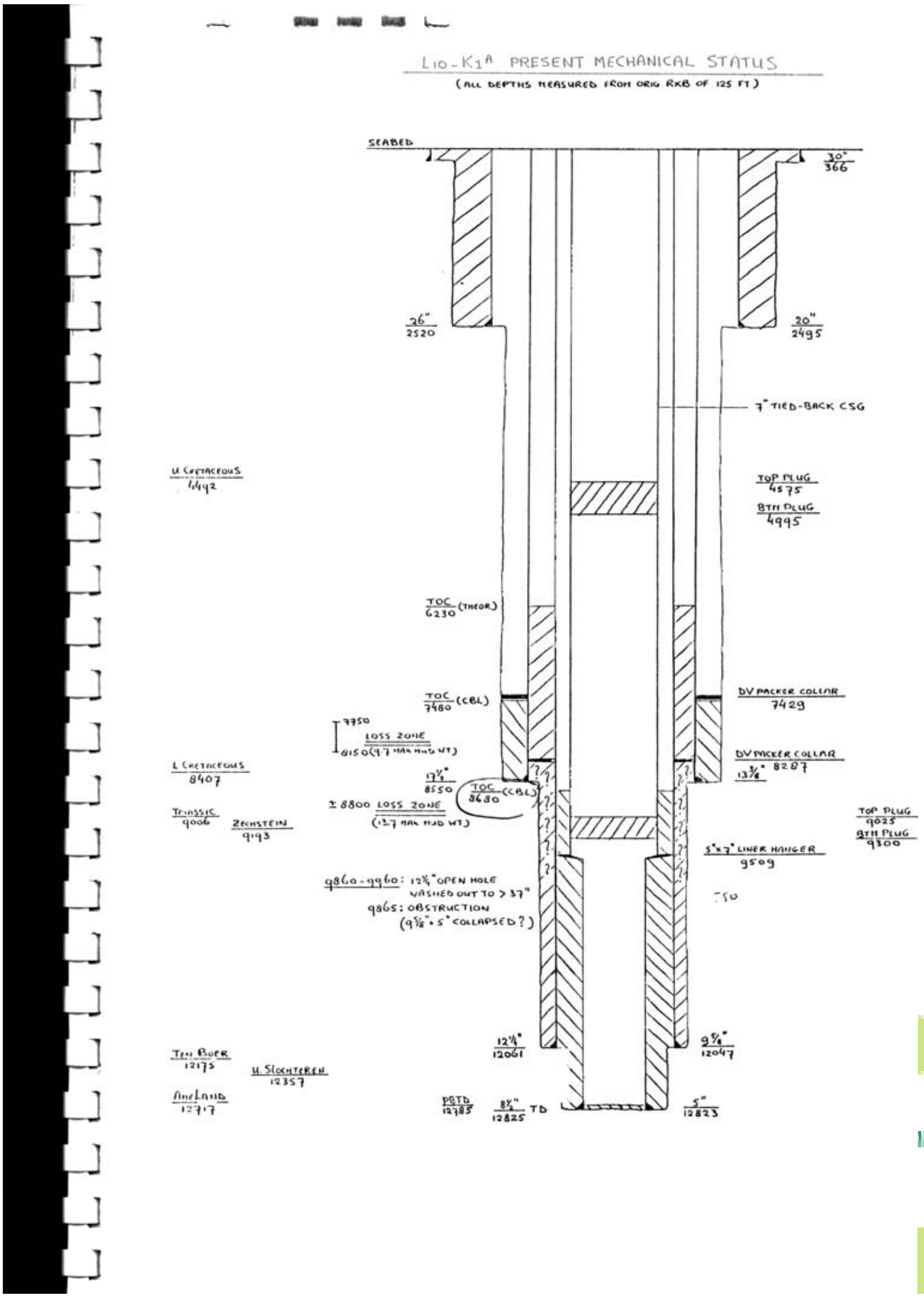
9 5/8", 53.3 lbs/ft, P110	548 bar
10 ¾", 109 lbs/ft, P110	1317 bar
7", 32 lbs/ft, P110	744 bar
7 5/8", 59 lbs/ft, P110	1442 bar
5", 18 lbs/ft, P110	928 bar





L10 fields-prospects

L10-K1A



L10-K1A PRESENT MECHANICAL STATUS
(ALL DEPTHS MEASURED FROM ORIG RKB OF 125 FT)
SEABED
30" 366
26" 2520
20" 2495
7" TIED-BACK CSG
U CRETACEOUS 4492
TOP PLUG 4575
BTM PLUG 4995
TOC 6230 (THEOR)
TOC 7480 (CBL)
DV PACKER COLLAR 7429
7750
LOSS ZONE
8150 (9.7 MAX MUD WT)
L CRETACEOUS 8407
DV PACKER COLLAR
13⅜" 8287
17½" 8550
TOC 8680 (CBL)
± 8800 LOSS ZONE
(12.7 MAX MUD WT)
TRIASSIC 9006
ZECHSTEIN 9193
TOP PLUG 9025
BTM PLUG 9300
5"x7" LINER HANGER 9509
9860-9960: 12¼" OPEN HOLE WASHED OUT TO > 37"
9865: OBSTRUCTION (9⅝" + 5" COLLAPSED?)
12¼" 12061
9⅝" 12047
TEN BOER 12175
U. SLOCHTEREN 12357
AMELAND 12717
PBTD 12785
8½" 12825 TD
5" 12823

Cost

10 ¾" versus 9 5/8"	approx. 100 Euro/m extra
7 5/8" versus 7"	approx. 100 Euro/m extra
Extra running time:	approx. 15000 Euro/job
Total for 500 m section	approx. 65000 Euro

Salt expectations: where one should hope for the best and fear for the worst

Bert de Wijn
Wintershall

During the years of exploration on the Dutch Continental Shelf, Wintershall has encountered a number of problems while drilling the salt sections of the Triassic, Zechstein and Rotliegendes. In the past these problems were, for convenience, related to squeezing salt, although later analyses suggested that this was not completely true. Therefore, the identification of the cause of these problems becomes the main way that leads to the prevention, cure and control of these high cost events. The problems can be divided in a number of classes by asking questions such as:

- Does it happen during the drilling process or after drilling (after casing has been run)?
- Where does it occur (geography)?
- When does it occur (While drilling and testing or later, during production)?
- Is it geology related (mineralogy, pressure (tectonics))?
- Is it related to drilling parameters (mud weight and type)?
- Or is it a relationship between one ore more of the above?

From this identification process geographical areas can be identified where problems occur most frequently and that can be related to a certain geological setting. The next step is the cure in drilling terms (pre-job planning), which involves such decisions as the selection of the mud type, casing design and the building of a decision tree to minimize any unusual problems that may be encountered.

Therefore, the overall planning process involves the close, open-minded interaction between the geoscience and drilling personnel with the ultimate goal of minimizing the negative financial effect on the drilling budget of any well.

Salt Expectations

Where one should hope for the best and prepare for the worst

Bert de Wijn
Trevor Barton
Willem Kwakernaak

Wintershall
BASF Group

Introduction

- “Squeezing salts” have been attributed as the cause of many drilling related problems from casing collapse to lost BHA’s and uncontrollable kicks.
- Should we assign the blame to “squeezing salts” or we should we be looking for the real causes of the problems encountered while drilling salt sections?
- Ultimate goal is to minimize the negative financial effect on the drilling budget without increasing the risk to the well.

wintershall
BASF Group

Some Questions

- Where are the main problem areas (geography)?
- Do problems happen during the drilling process or after drilling (after casing has been run, during testing or later, during production)?)?
- Are the problems geology related (mineralogy, pressure (tectonics))?
- Or are they related to drilling parameters (mud weight and type, wellbore shape or casing scheme/type)?
- Or is it a relationship between one ore more of the above?

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The Wintershall Salt Drilling Experience

- Success depends upon the combination of:
  - Knowledge of Stratigraphy of the salt sequence
    - Mineralogy
    - Where to expect problems
  - Tectonic history
    - Floaters and their avoidance
    - Fault mapping in salt
    - Pressures and temperature
  - Mud type and weight to be used
  - Planning and preparation
  - Luck

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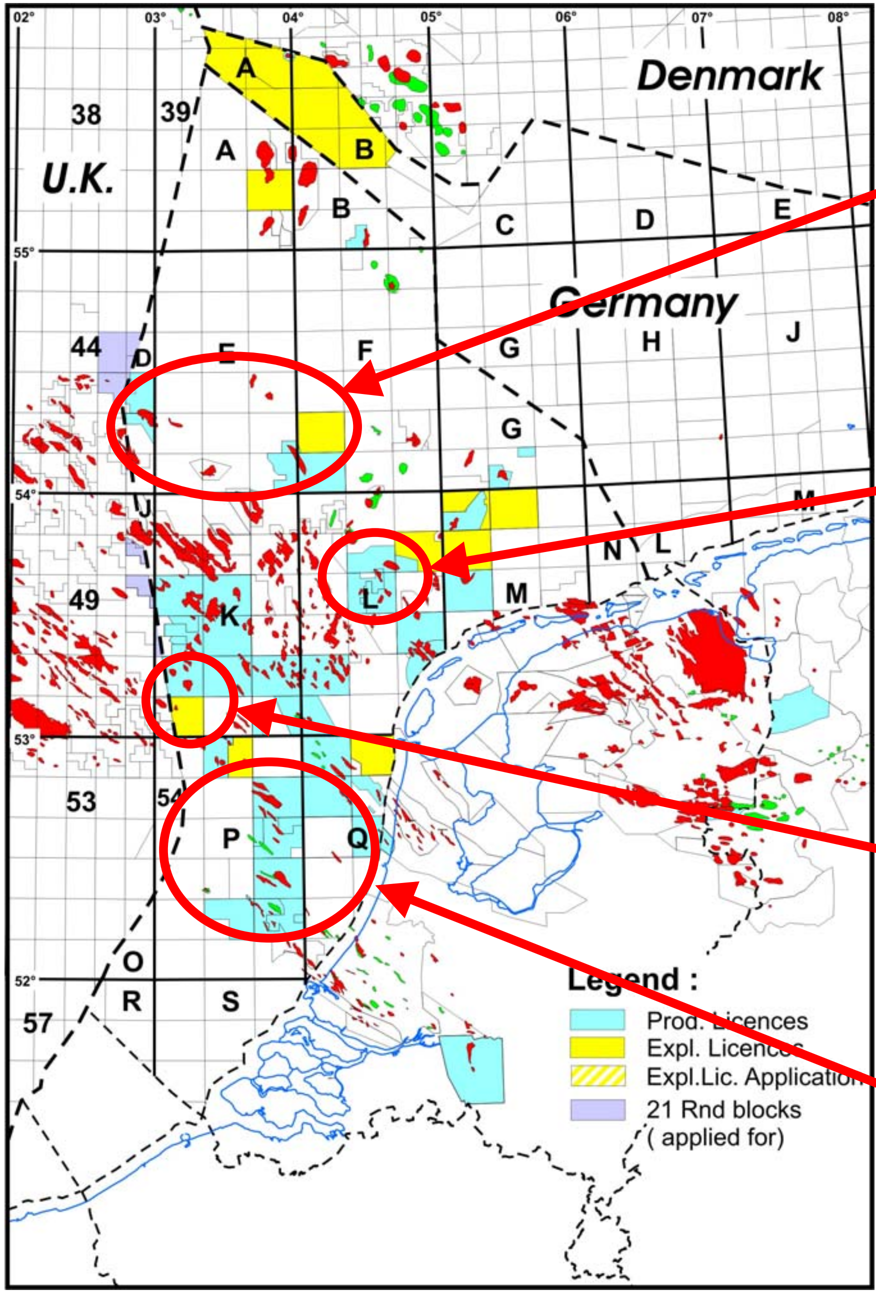
Where on the Dutch Continental Shelf?



D, E & F Area:

E13-1, D15-FA101, F16-3

L8 & L5 Area:

L8-5, L8-6, L5-9

K10/K13 Area:

K10-B wells, K10-V wells

P & Q quads:

No "squeeze" problems

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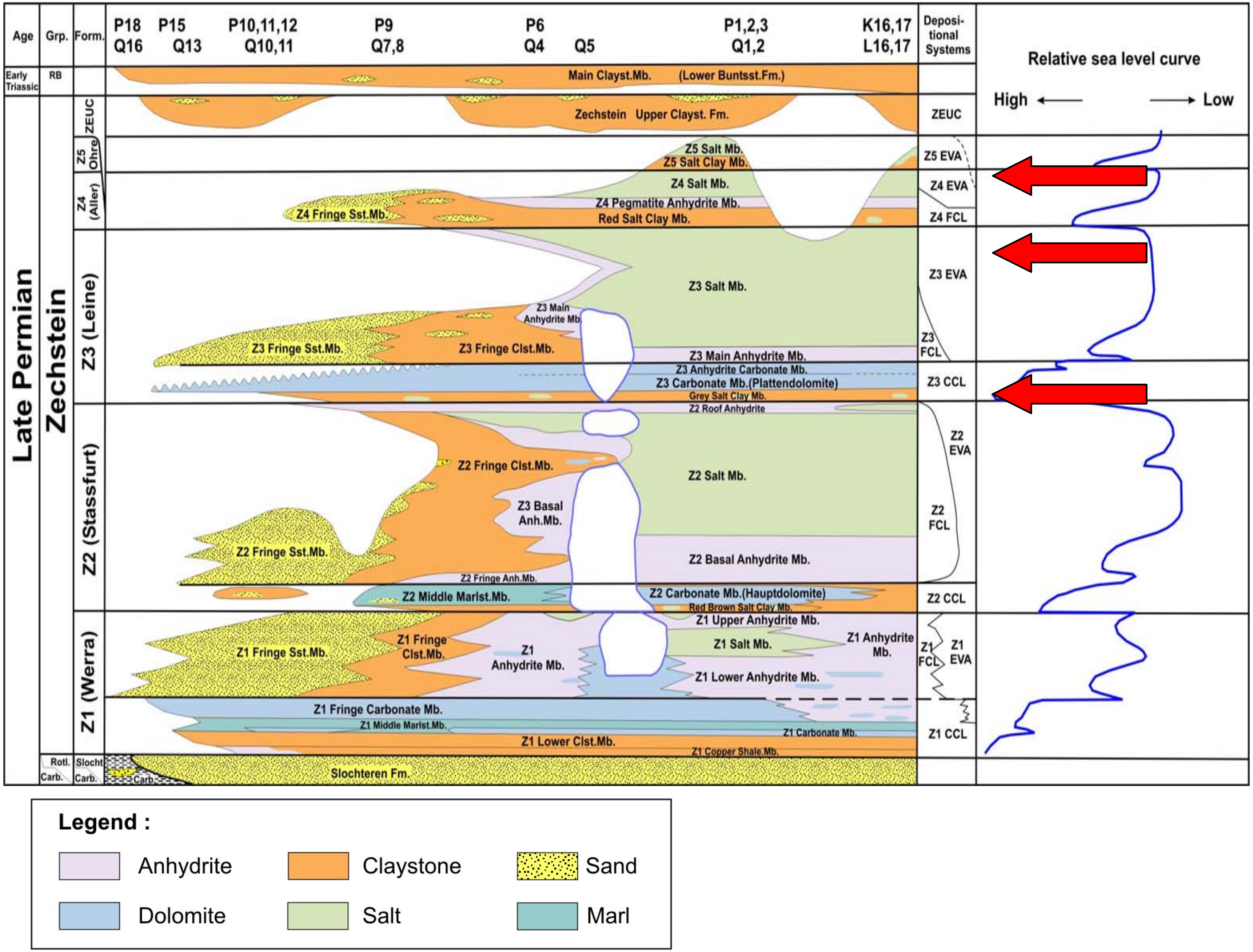
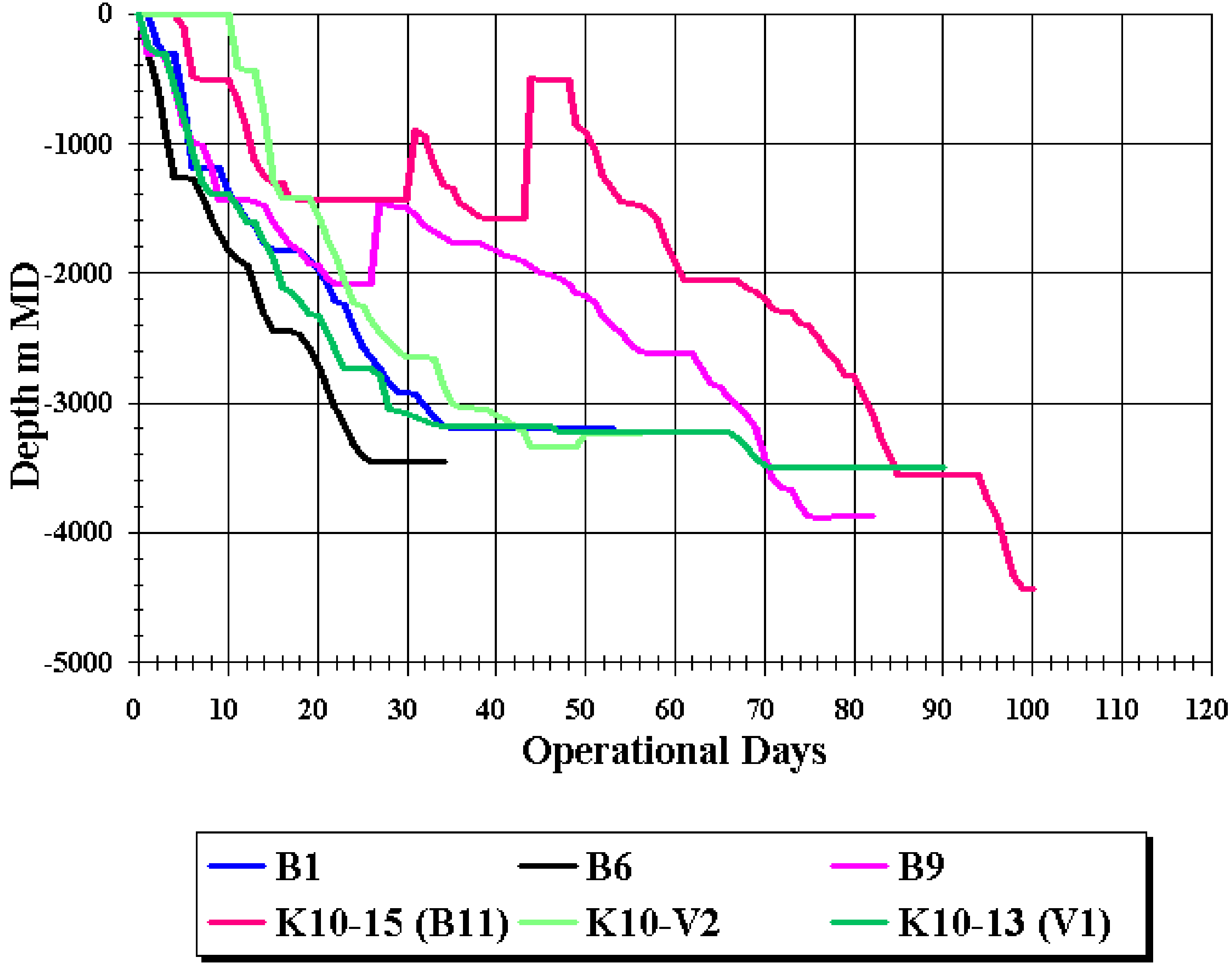
Zechstein Lithostratigraphy of the Southern N S



K10 Drilling Time Curves – Triassic salts



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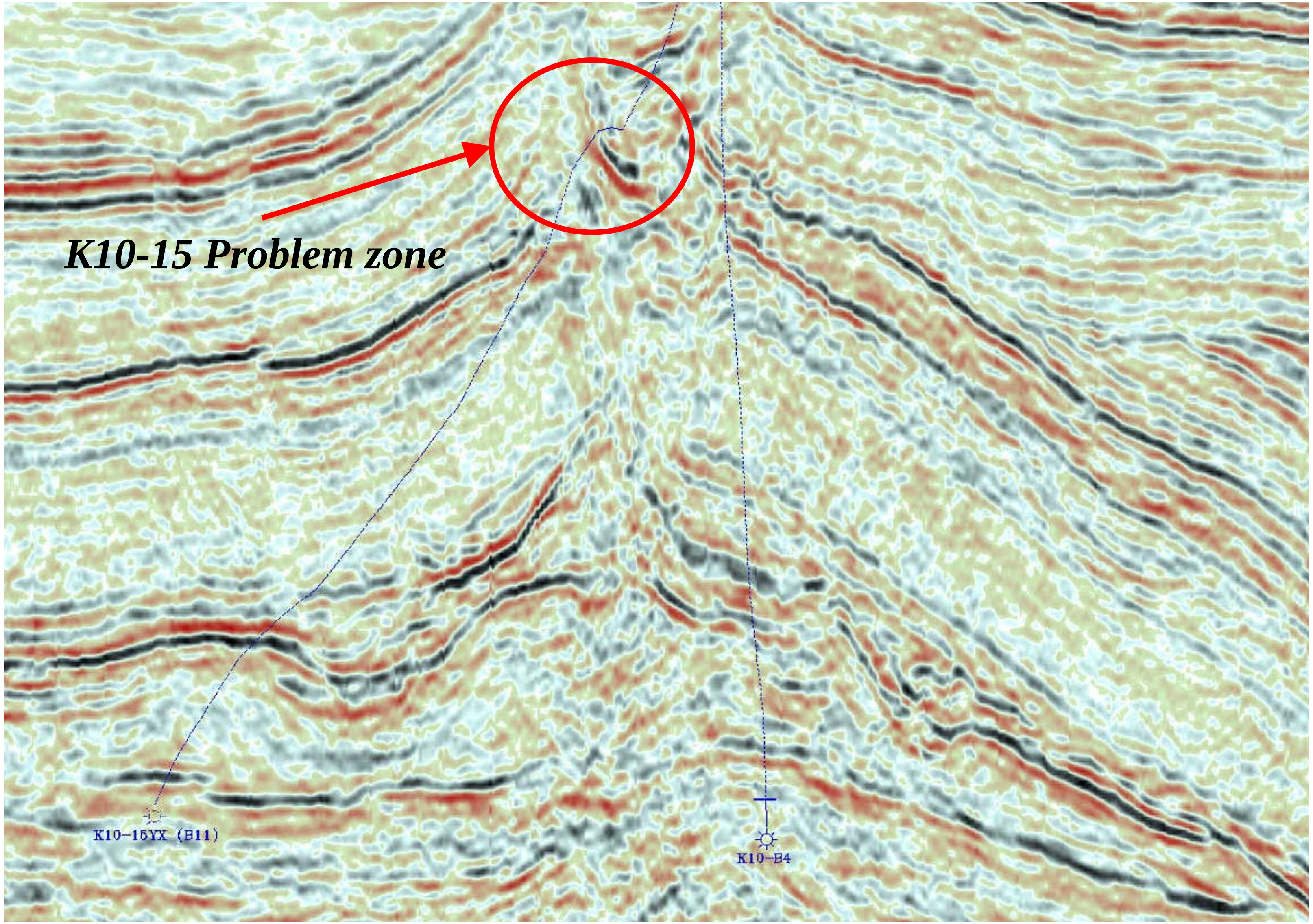
K10-B Field



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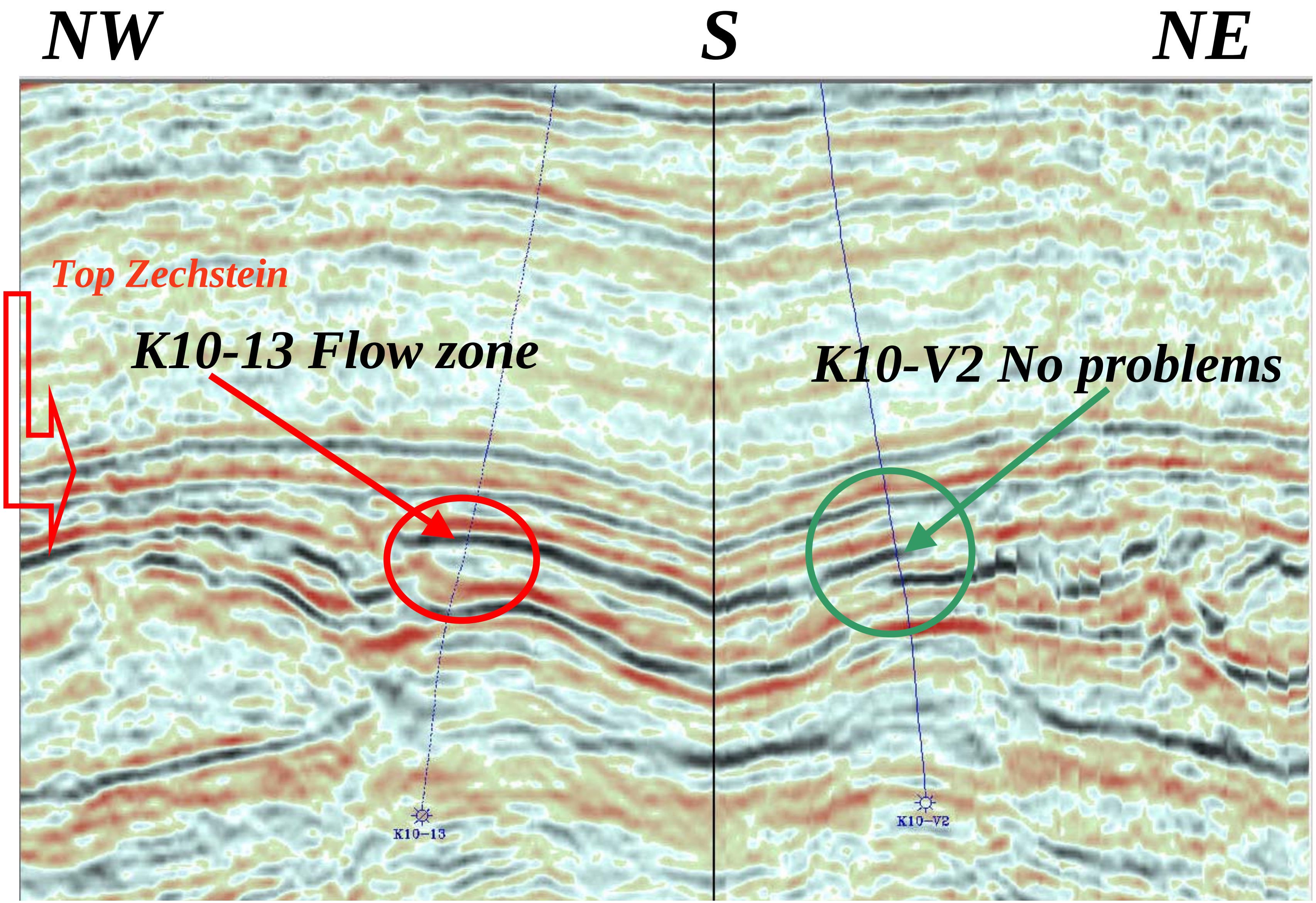
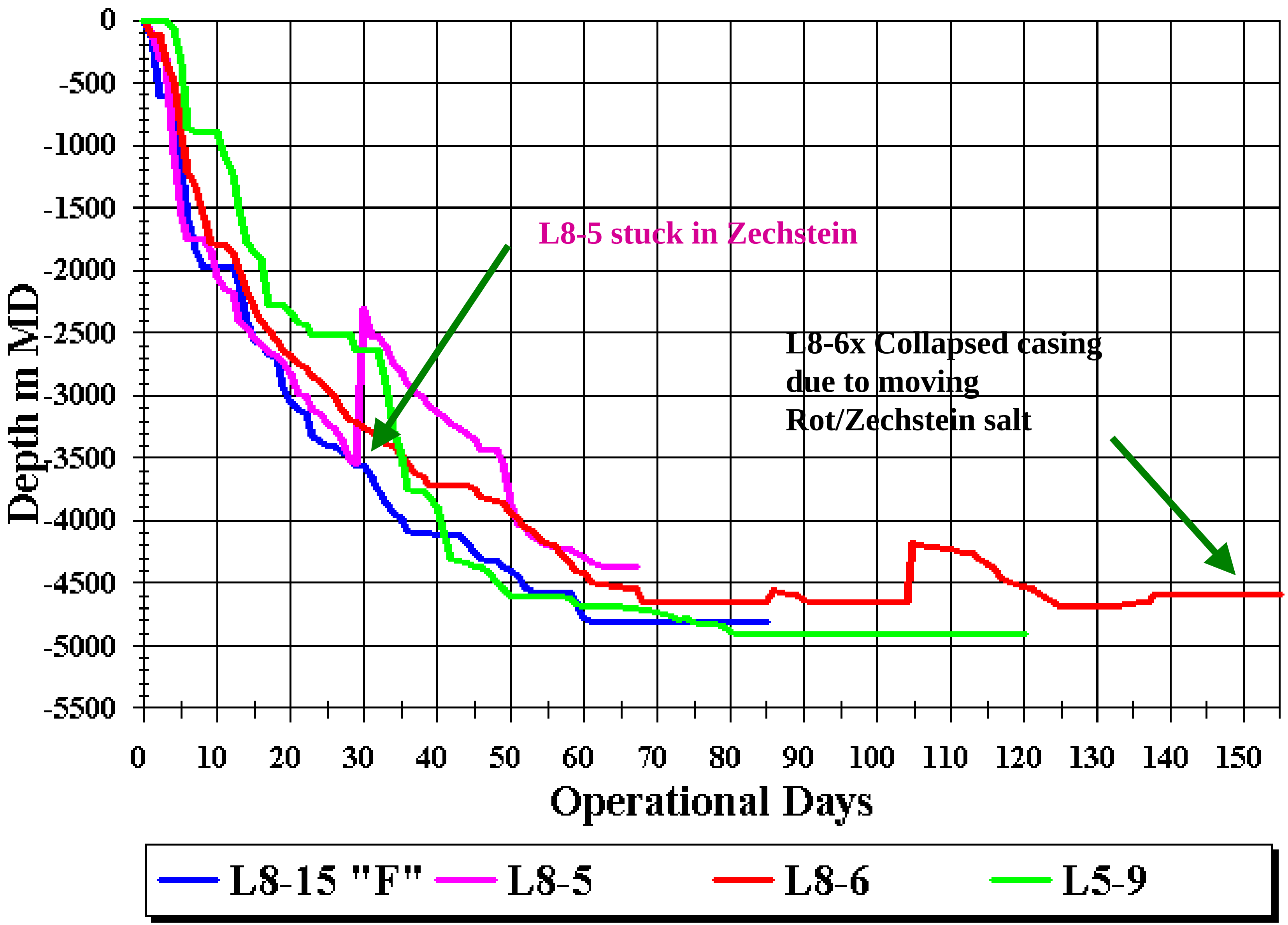
K10-Victor

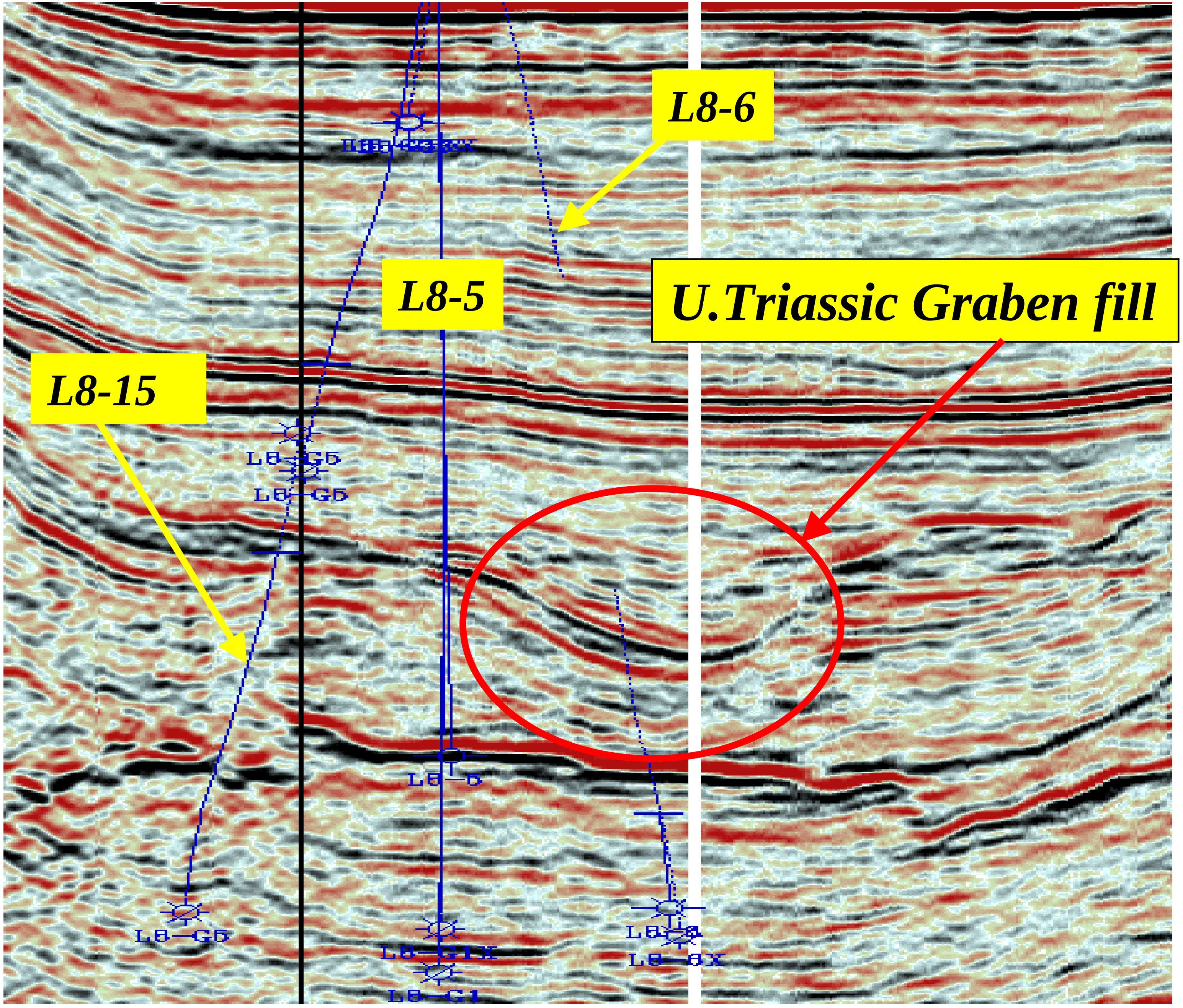


NW
S
NE
Top Zechstein
K10-13 Flow zone
K10-V2 No problems
K10-13
K10-V2

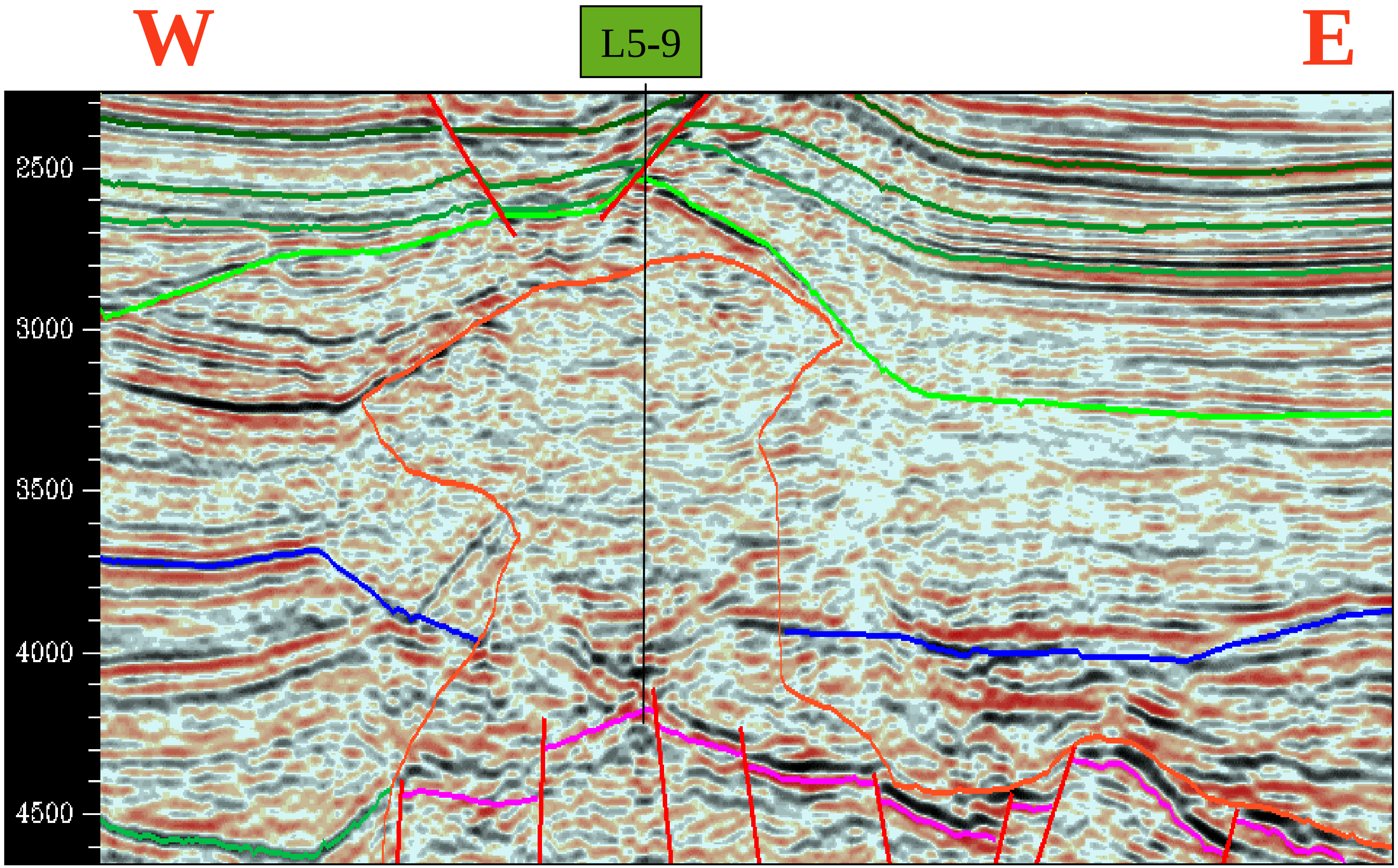
L8/L5 Drilling Time Curves – Zechstein Salts



L8-Golf Field



Salt Domes – Structures to be avoided?



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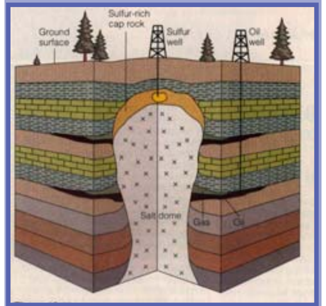
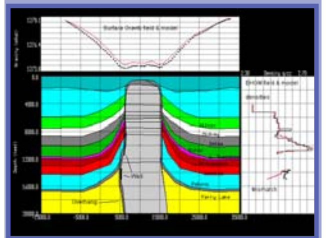
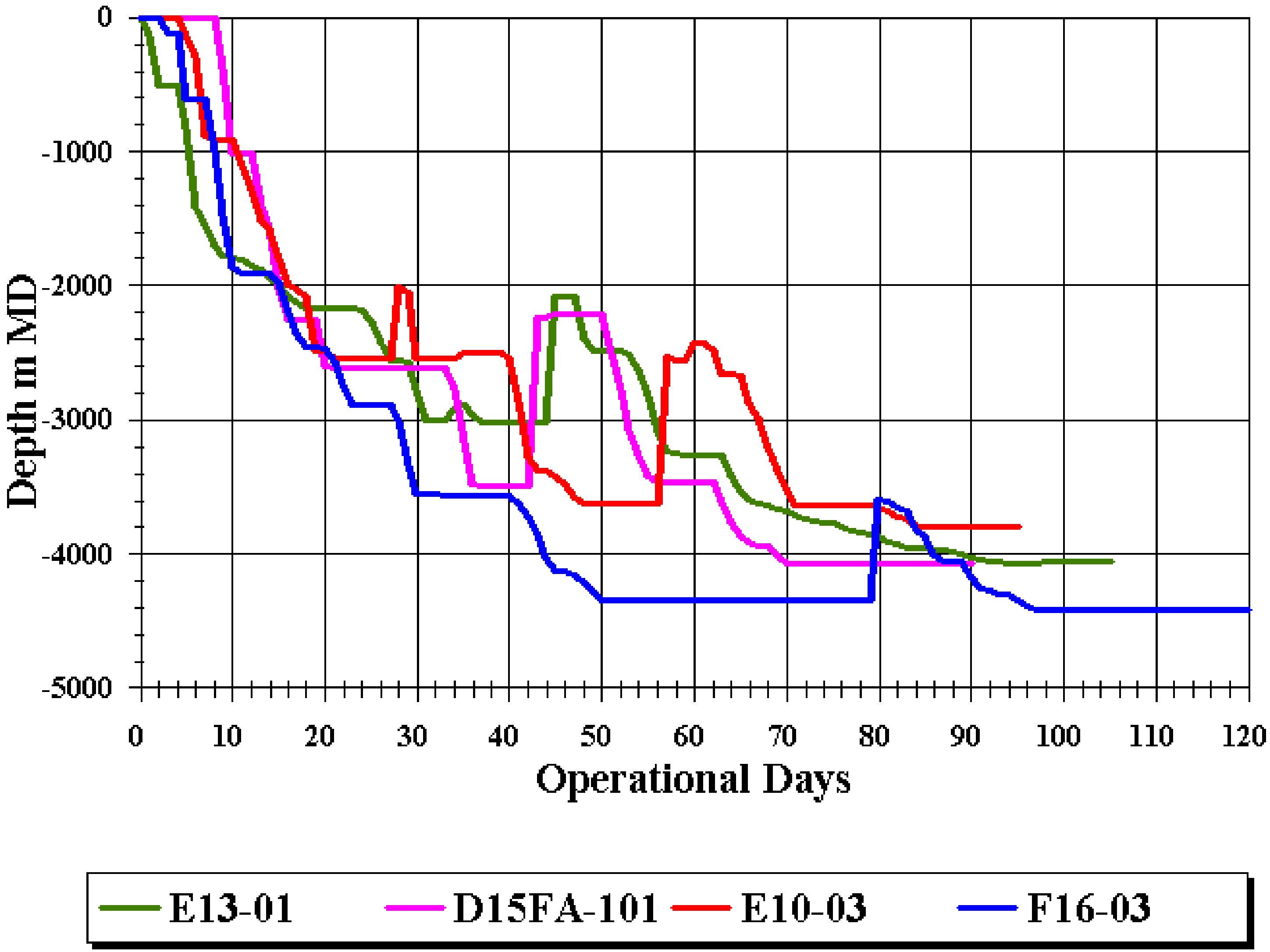
Salt Domes

- When drilled in the center tend to be force balanced
- High drilling speeds
- Difficult to detect “floaters” on seismic
- Need careful risk assessment
- Depth conversions become problematic
- Given the right planning – Why not drill it but be prepared!

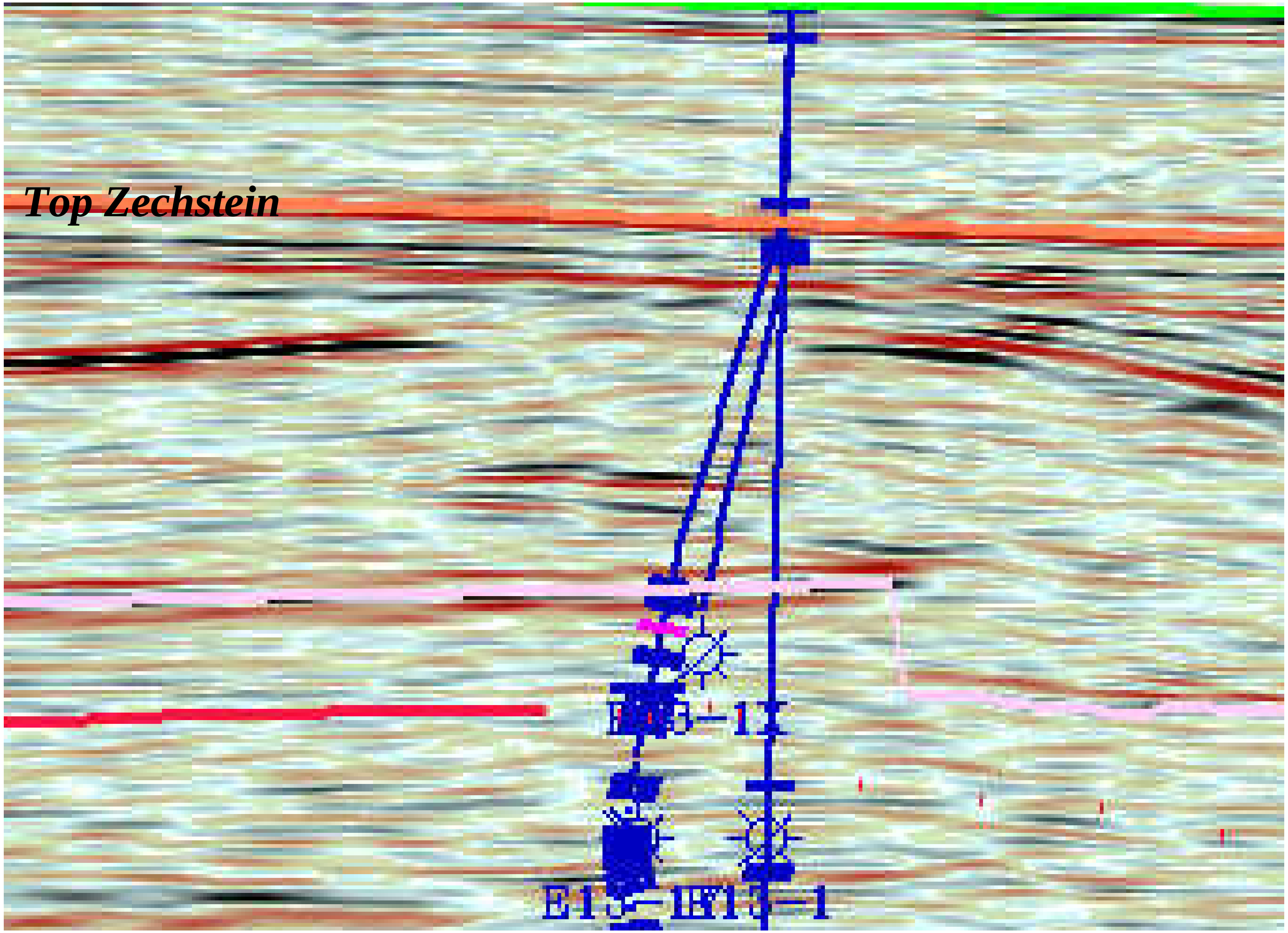




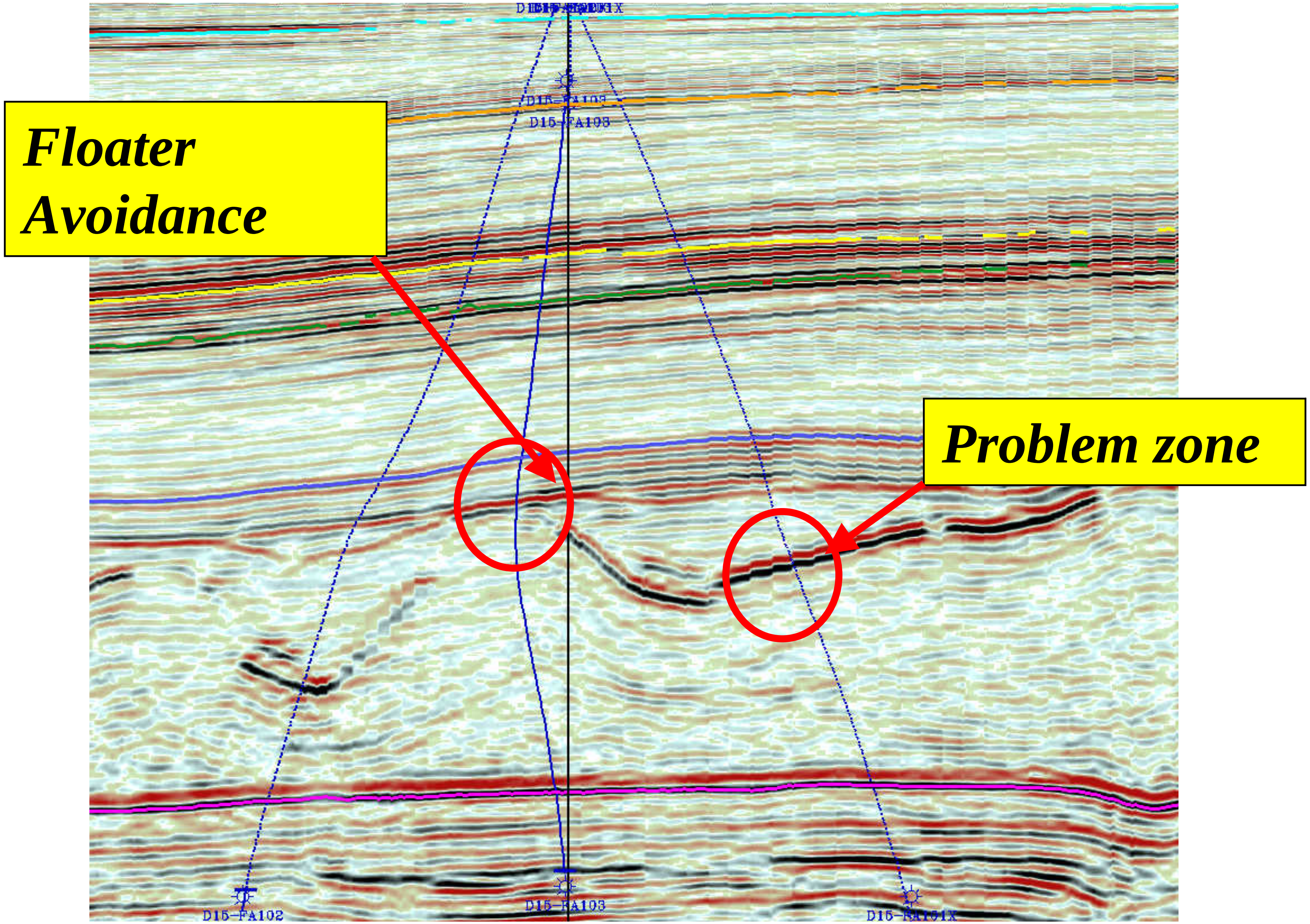
D, E & F Blocks Drilling Time curves – Triassic, Zechstein & Rotliegend Salts



E13-1 First Well With "Flowing Salt"



D15-FA



Floater Avoidance
Problem zone
D15-FA103
D15-FA102
D15-FA103
D15-FA101X

Mud type

- OBM or WBM
  - Choice based on objectives and local knowledge combined with risks assessment.
  - Each type has its advantages, disadvantages and consequences.

	Advantages	Disadvantages
OBM	■ Gauge Hole ■ OH Wireline logging	■ Water flows ■ Cannot flow / drill ■ Expensive when problems
WBM	■ Cheaper when problems ■ Water flows ■ Flow / drilling	■ Poor Gauge holes ■ Logging through casing - GR & Sonic

Rafts/ Floaters

- Zechstein floaters
  - Map out and use 3D visualization to demonstrate the problems to others
  - If there is no other way but to drill it then be prepared for the worst and hope for the best.
- Why sometimes overpressure and other times not
  - Sealed and uplifted
  - Requires the development of porosity and permeability e.g. fracture development in anhydrites
  - Charged from elsewhere and sealed
  - Mineralogical changes release water
  - No porosity or permeability – then no kick potential

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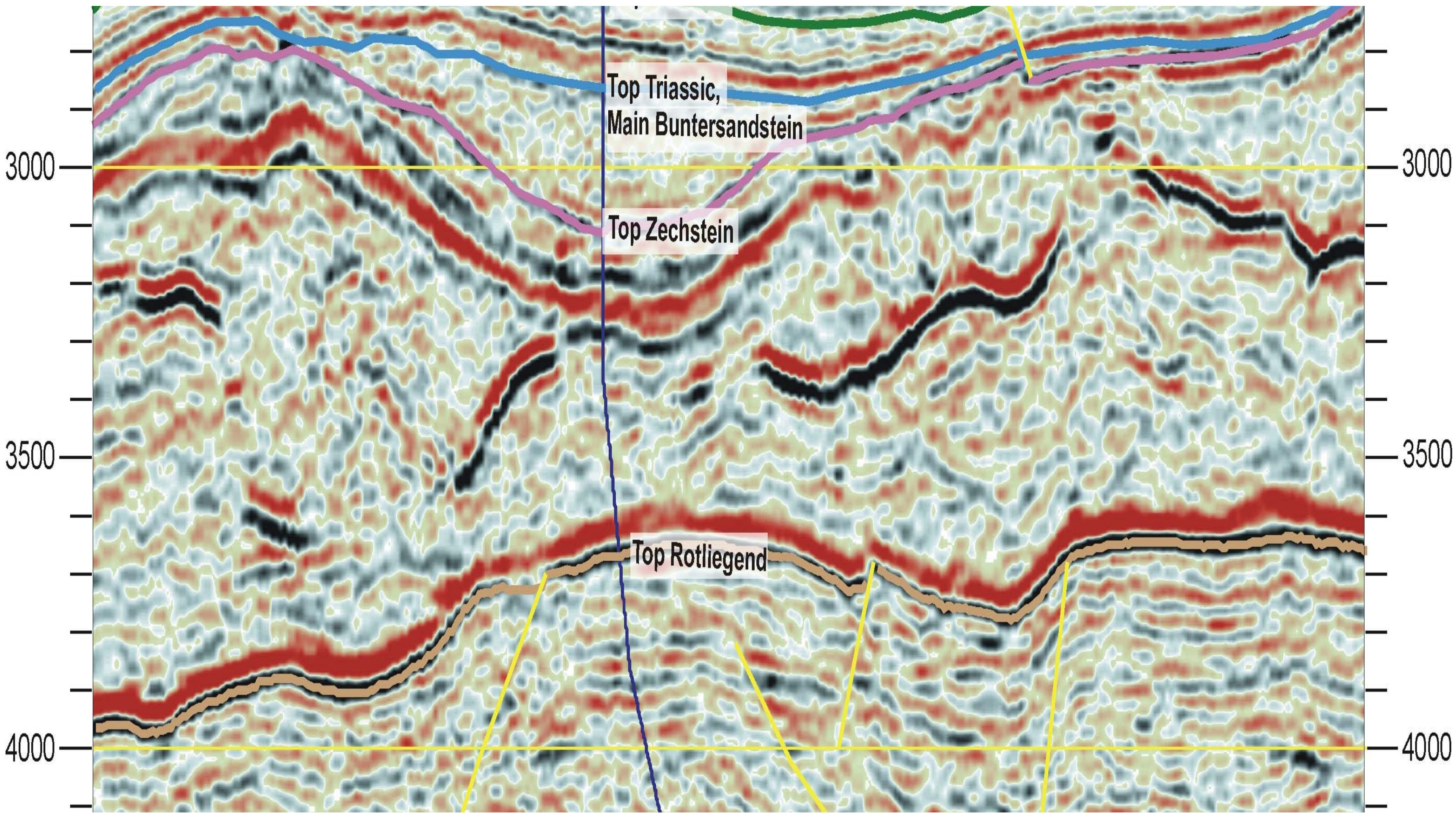
Floaters Seismic Picture

F16-5



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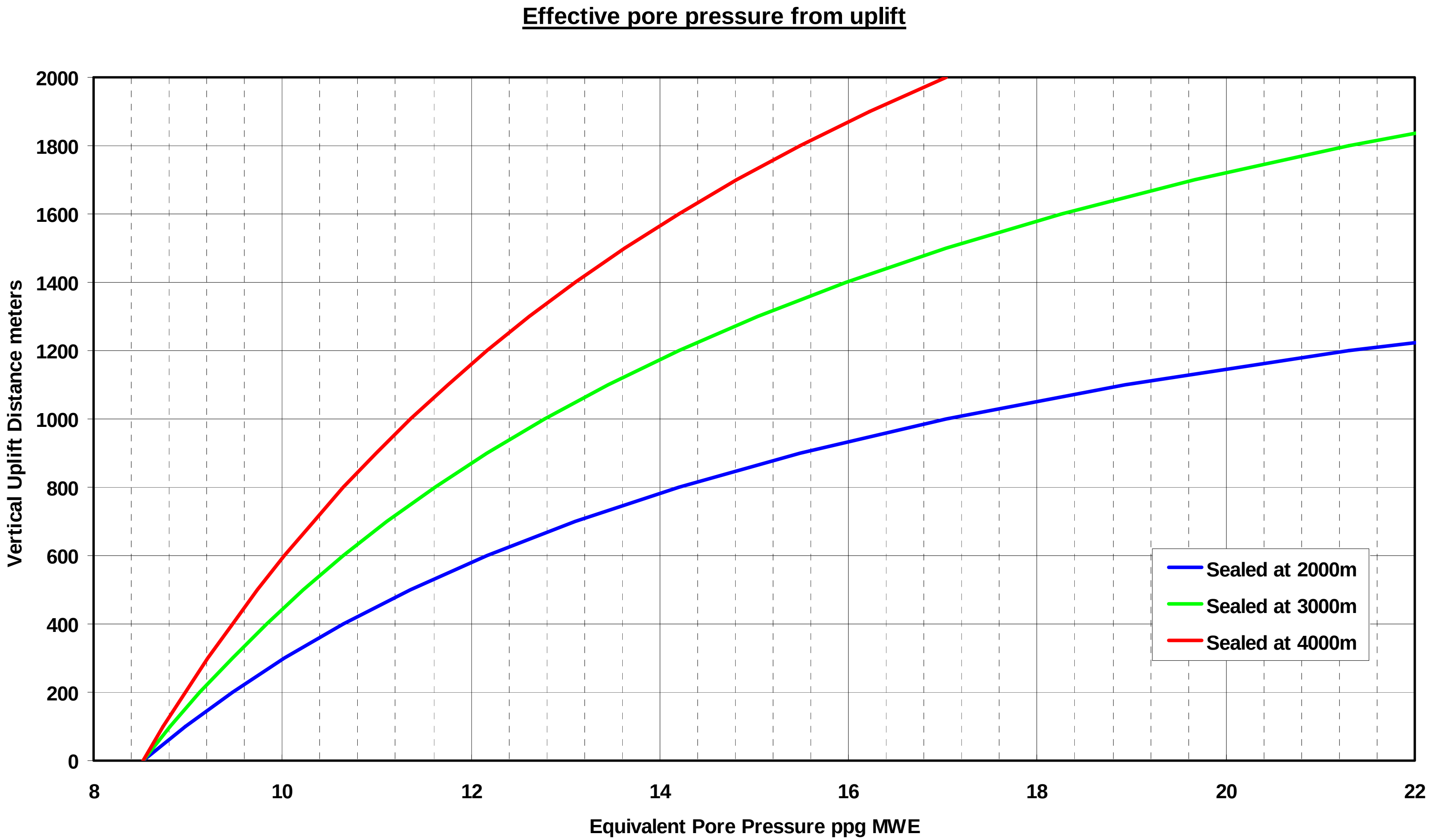
Burial history

- Natural sealing and uplift creates overpressures



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Other Problems

- Control kick with mud weight and experience loss in the lower section carbonates
- Flowing salt: (E13) type of salt: Carnalite/Polyhalites?
- Temperature definition – is there a critical temperature?
- Does the hole angle problem worsen the problems?

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What have we learned so far?

- Selection of the mud type and weight are important
- Casing schemes are critical to the success of the well
- Triassic/Rotliegend salts move later so plan to have proper casing (weight) in place
- Design the well path to avoid floaters when possible
- Problem and risk decision tree must be in place before the well is drilled
- Have a good team with a good mix of experienced drillers and geologist who can listen to each other

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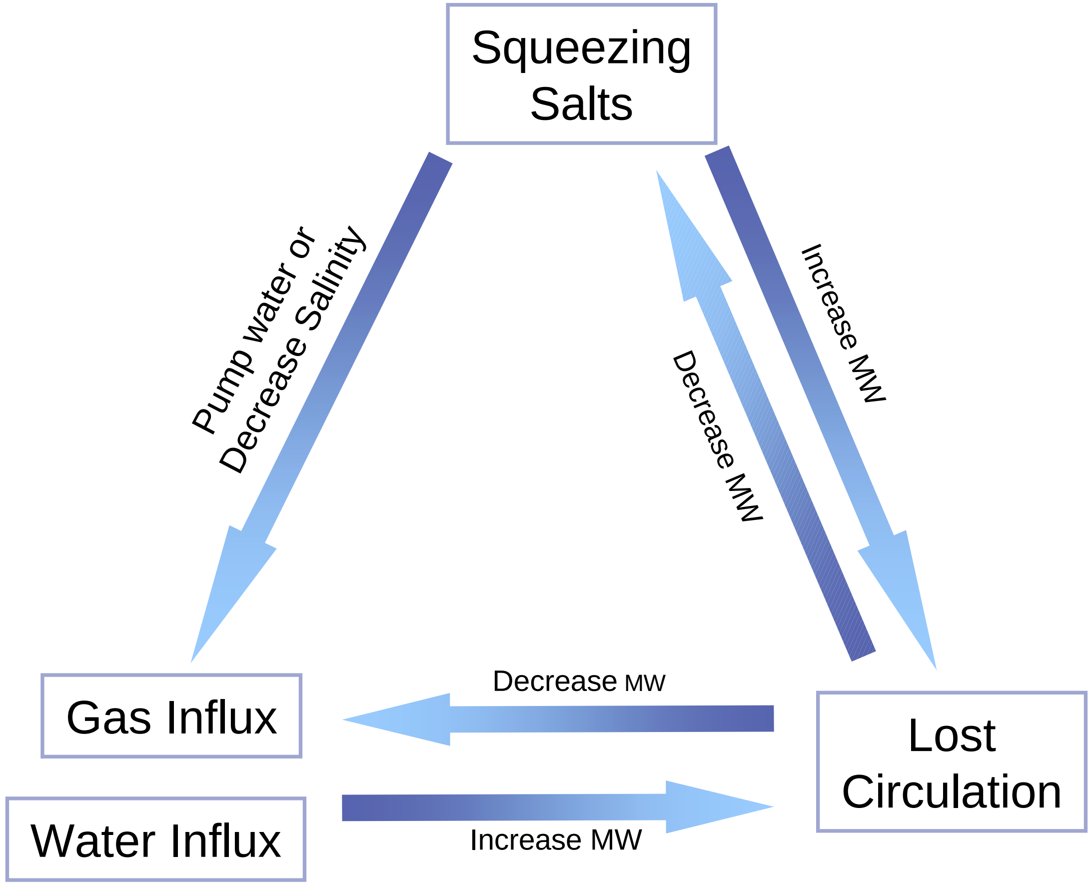
Remember Catch 22



Planning and Preparation are Paramount

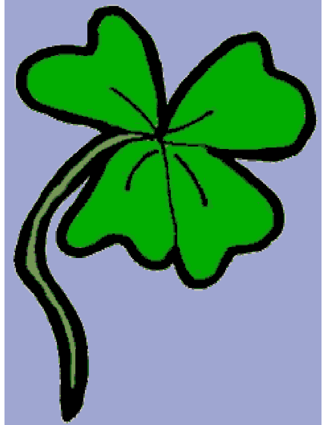
- Investigate the surrounding area
  - Map of Zechstein, thickness, temperature and previously encountered problems
  - Areas where there are Triassic and Rotliegend salts
  - Understand the structure
    - What are the main structural hazards
      - Map floaters and target holes
      - Map faults in Zechstein whenever possible
      - Risk assess salt domes
- Well design
  - Select appropriate mud systems.
  - A well designed well path, casing & drilling scheme.
- Be prepared for problems when they occur.
  - Be able to make rapid decisions to such as:
    - Weight up mud, flow-drill or kill depending on the circumstances.
  - Have well informed, responsible and communicative people.

We are not alone

- Experience elsewhere can lead to understanding the processes involved.
  - Germany salt mining
    - Large roads in salt domes
  - UK Boulby salt mine
    - Potash salt flows
  - NL Onshore salt cavern experiences
    - (this symposium)

Conclusion

- We must learn to predict where to expect problems using seismic or any other tools we can find
- Lots of effort, time and money have already been invested but it is foolish to be cheap
- Unlucky is when you encounter a BHA loosing problem but the side-track within a few meters of the original borehole does not encounter either the formation or its associated problem
- Experience, understanding and preparation are hard to beat BUT
    - LUCK IS STILL NEEDED



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An overview of squeezing salts offshore and onshore the Netherlands

Paul Reemst & Mark Geluk
Nederlandse Aardolie Maatschappij, P.O. Box 28000, 9400 HH Assen, the Netherlands

When drilling towards Rotliegendes reservoirs one of the most critical overburden sections in terms of drilling hazards is the Zechstein. This interval consists of a series of evaporitic sediments deposited in a large-scale basin during the late Permian. Most Zechstein drilling hazards are well known: Kicks and losses can occur in the lower carbonates (ZEZ1C and ZEZ2C) and in the ZEZ3C “floaters”. Brine flows occur in various salt sections. Of particular interest for this workshop is the occurrence of so-called “squeezing salts”. These are highly mobile and ductile K-Mg salts that can “grab” the drill string and may damage the casing after drilling.

The squeezing salts have been encountered in the upper parts of the Zechstein 2H, 3H and 4H formations in the Zechstein Basin. This basin spreads from eastern England in the west, to Poland in the East. The sediments were deposited during five main cycles of sea-water influx in the basin. Evaporation of the water influx resulted in a series of clays, carbonates, anhydrites and salts. Each of the main cycles consists of minor sub-cycles causing a complex geographical spread of the various formations. The basal part of a Zechstein series consists normally of a thin clay layer followed by carbonates (e.g. ZEZ3C), which are thickest at the margin of the basin. Typically the carbonates are overlain by a series of anhydrites (e.g. ZEZ3A) and salts (e.g. ZEZ3H). Within each salt sequence a marker bed of Polyhalite, a non squeezing K-Mg salt, can be regionally correlated. The squeezing salts which are the most soluble salts form the upper parts of an evaporitic series, deposited in isolated ponds in the center of the basin.

The squeezing salt Carnallite, can be distinguished from other salts by its high gamma response (due to high K content) and low density and is therefore mappable on a regional scale. Due to its neutral gamma response, Bischoffite is less easy to correlate regionally. The main occurrence of squeezing salts is in the NE Netherlands and offshore K-blocks where they continue in the UK-sector. The regional depositional pattern is disturbed by later phases of halokinesis and structuration of the subsurface. Seismically the squeezing salts are best imaged in an inverted acoustic impedance cube, where they emerge by their low impedance.

In NAM it is practice to share all well-path issues in a pre-drill “well trajectory session” between G&G staff from assets and technical services, and well engineers and drilling engineers.

An overview of squeezing salts offshore and onshore the Netherlands

Paul Reemst
en
Mark Geluk

Talk outline

? Squeezing salt definition
? Depositional model
? Where can we find them?
? Can we predict them before we drill?

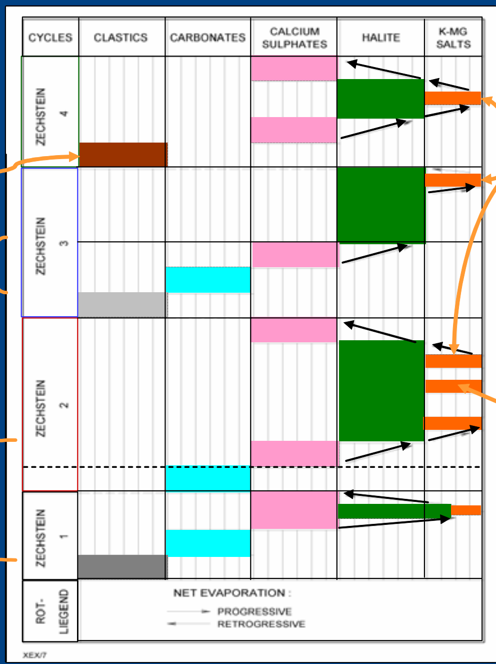
Squeezing salts: a potential drilling hazard
one out of many others in the Zechstein

Salt red mudstones: squeezing potential

ZEZ 3A & C: *Floaters*

"Basal Carbonates":

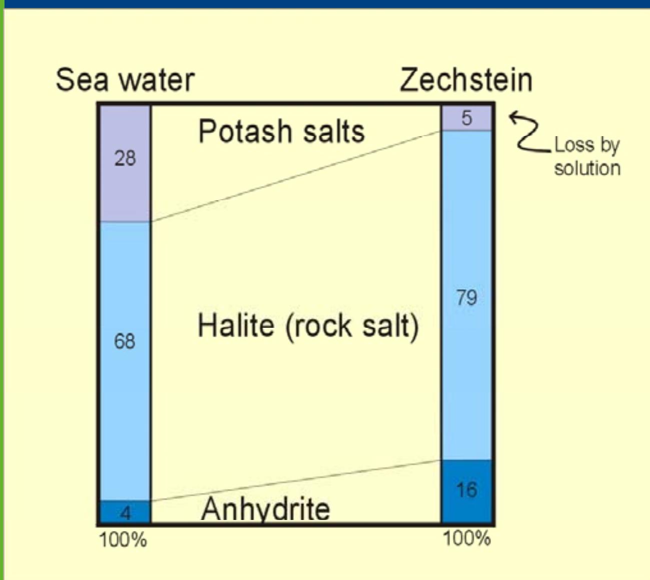
- ZEZ2A
- ZEZ2C
- ZEZ1W
- ZEZ1C



ZEZ4H, 3H, 2H *Squeezing Salts*

Polyhalite

Sea water composition versus sedimentary record



Zechstein forms a stack of evaporite cycles

Selley, 1976

Mechanical behaviour of Zechstein rocks

brittle- ductile

salt clay
carbonate
thick anhydrite
thin anhydrite in salt
rock salt (halite)
K-Mg salts

The original sedimentary bedding is maintained throughout the deformation of evaporites

Folded carnallite salts, Neuhof-Ellers, Germany (ZEZ1)

Overview of evaporite minerals

	Composition	GR readings (API)	Density	Sonic	Neutron porosity	Caliper	Squeezing
carnallite	$KClMgCl_2.6H_2O$	200	1.57	78	60+	normal	**yes**
sylvite	KCl	500	1.86	77-78	-3	normal	no
polyhalite	$CaK_2Mg(SO_4)_3.2H_2O$	190	2.79	57	25	normal	no
bischoffite	$MgCl_2.6H_2O$	0	1.54	100	60+	v. large	**yes**
halite	NaCl	0	2.05	67	-3	normal	no
anhydrite	$CaSO_4$	0	2.98	50	-2	normal	no
Kieserite	$MgSO_4.H_2O$	0	2.57	50	43	normal	no

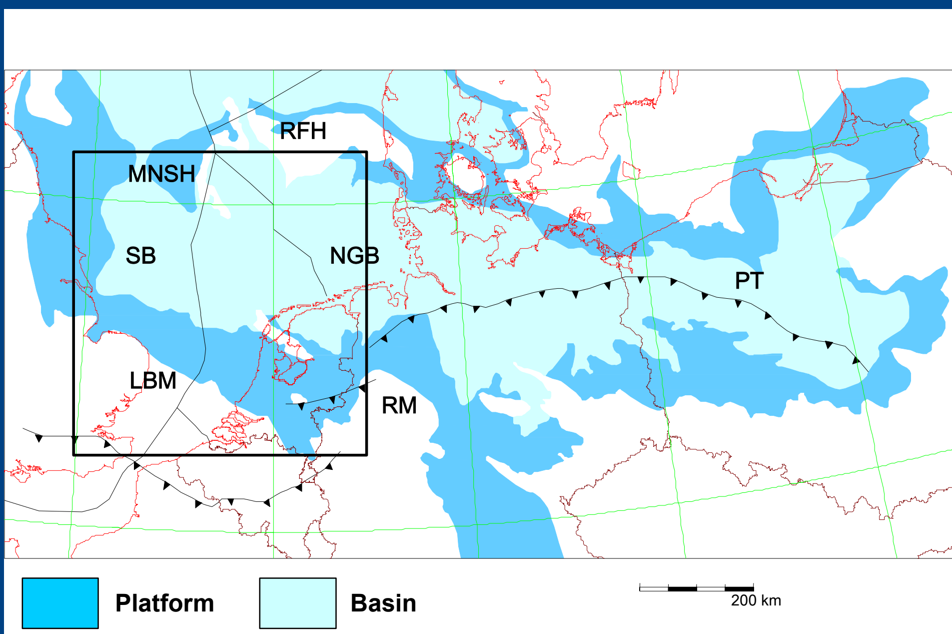
POTASSIUM-BEARING EVAPORITES

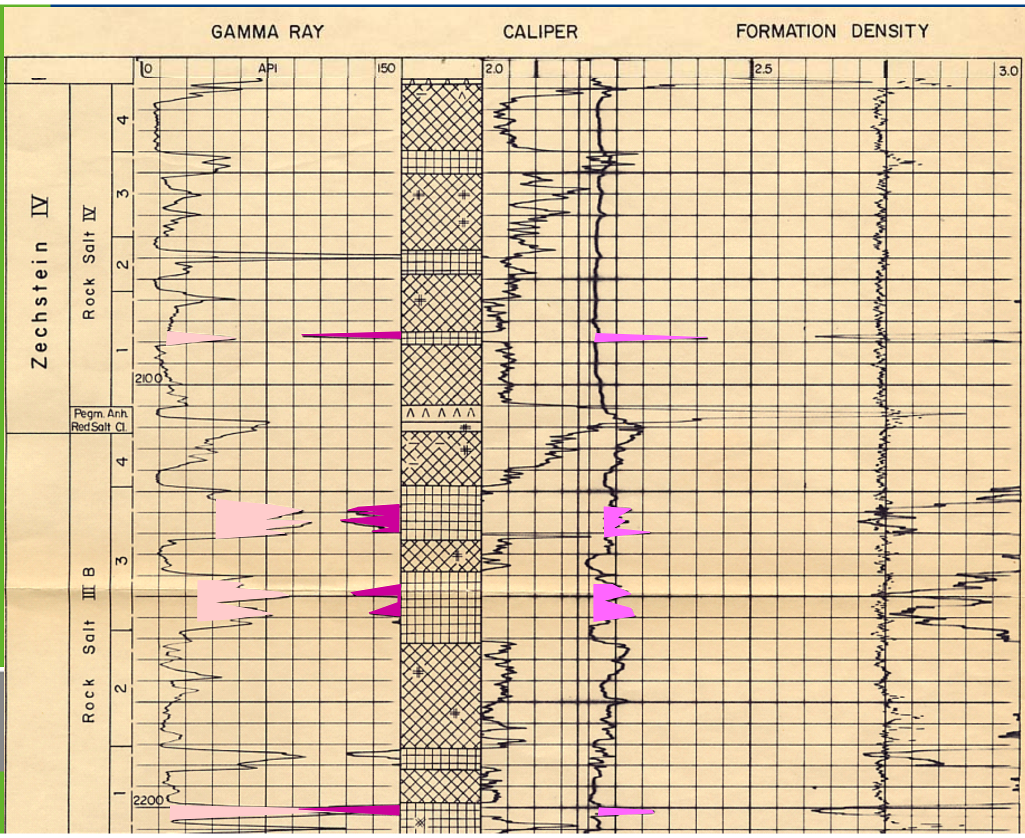
Name	Chemical formula	K content (% weight)
Sylvite	KCl	52.4
Langbeinite	$K_2SO_4(MgSO_4)_2$	18.8
Kainite	$MgSO_4KCl(H_2O)_3$	15.7
Carnallite	$KCl\ MgCl_2(H_2O)_6$	14.1
Polyhalite	$K_2SO_4\ MgSO_4\ (CaSO_4)\ (H_2O)_2$	13.4

gamma ray non conclusive:

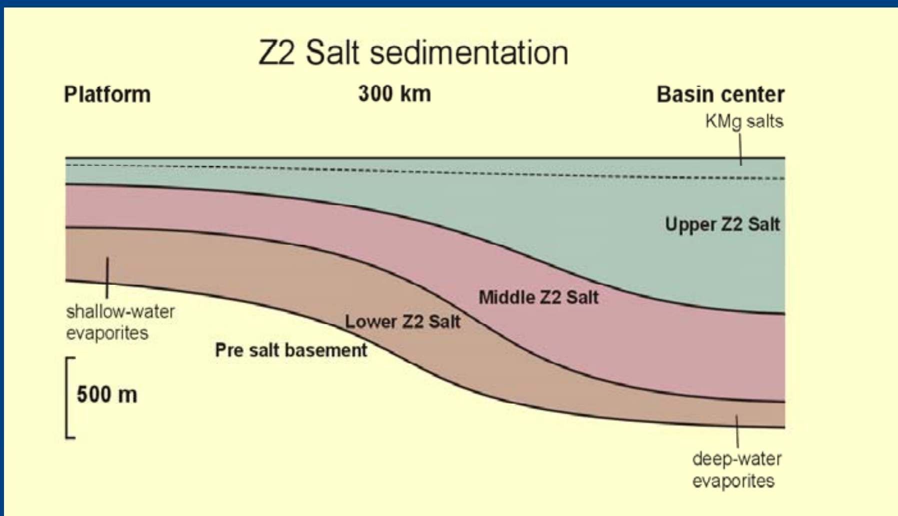
look for high gamma *and* low density!

Late Permian Zechstein Basin





Infill of a marine evaporite basin



? The infill is not a single event, but a complex system of polyphase sedimentation.

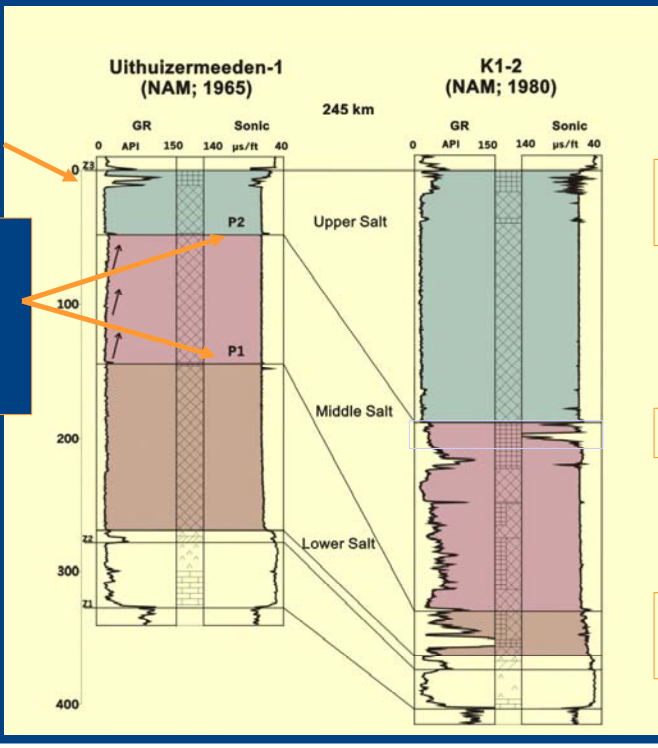
? The three stage salt sedimentation is separated by Polyhalite marker beds. The upper salt filled the relief.

? In the UK SNS the polyhalites often show brine flows and wash outs.

ZEZ2H Stassfurt Salt: internal layering

Typical log pattern

P1, P2: Polyhalite marker beds, regional correlatable

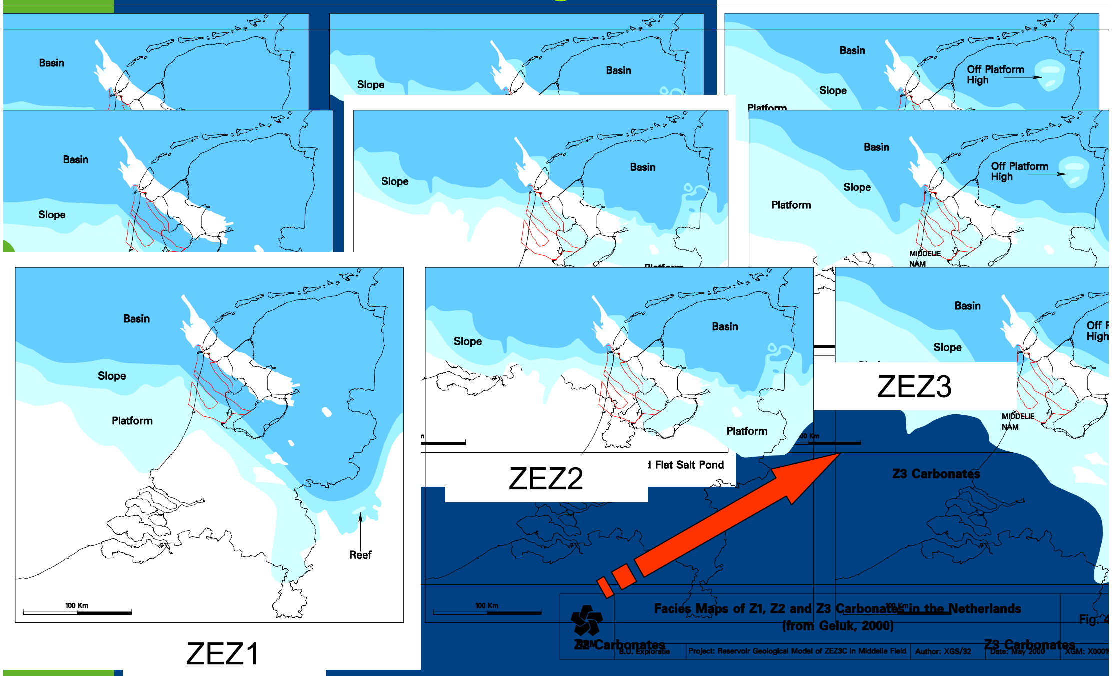


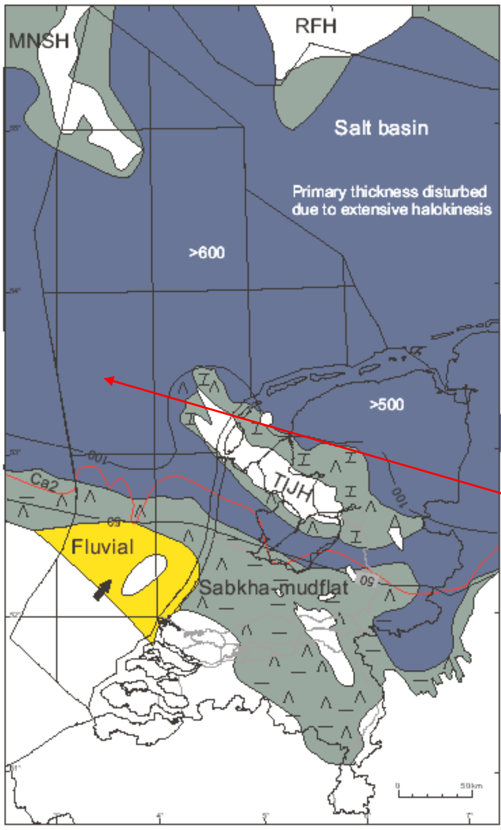
No squeezing salts?

Squeezing salts?

No squeezing salts

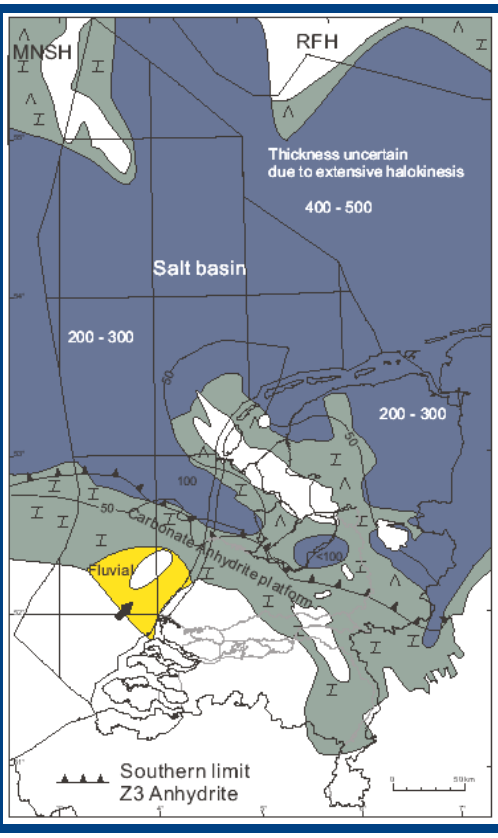
Evolution of the Zechstein Basin Through time



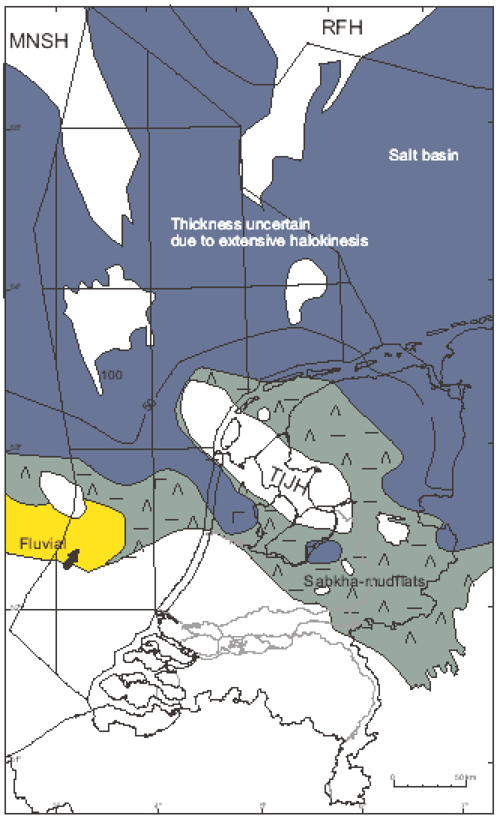


ZEZ2 salt

problem intervals occur very locally



ZEZ3 salt



ZEZ4 salt

Regional occurrence of squeezing salts:

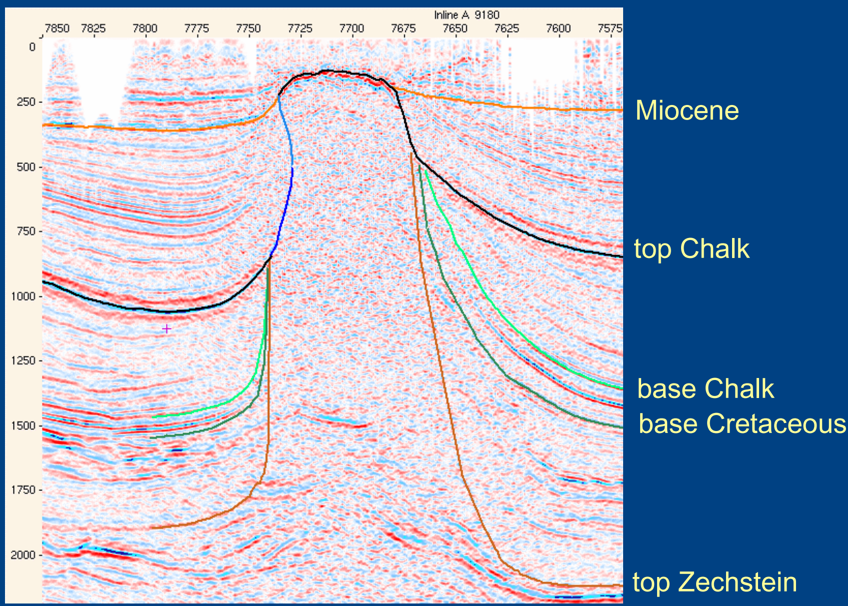
? Predictable

? Both stratigraphically and geographically

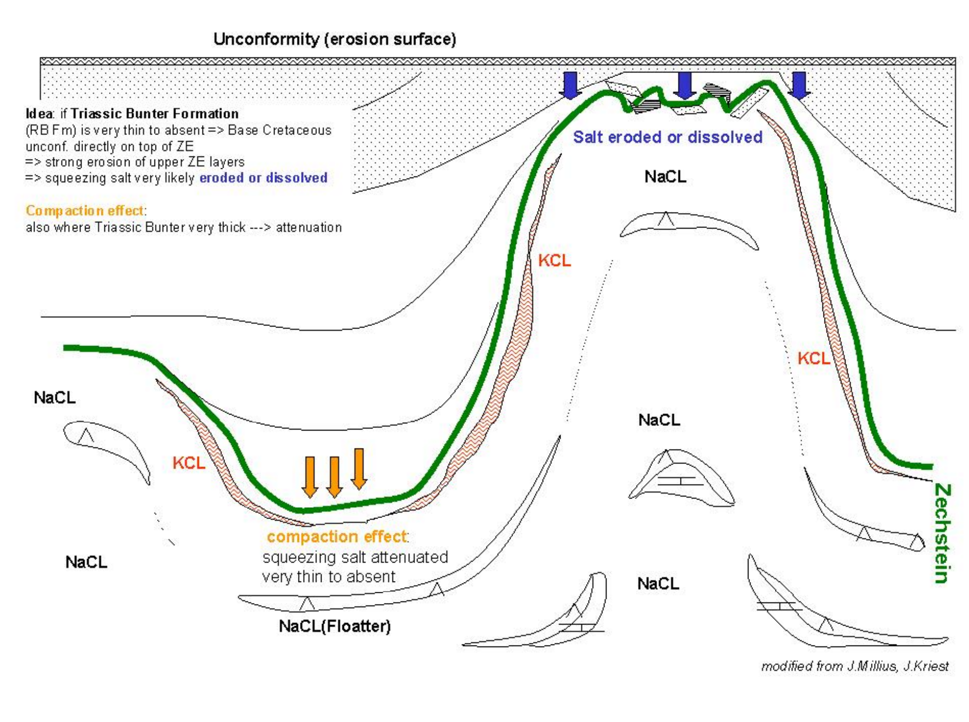
but:

? how about local salt domes?

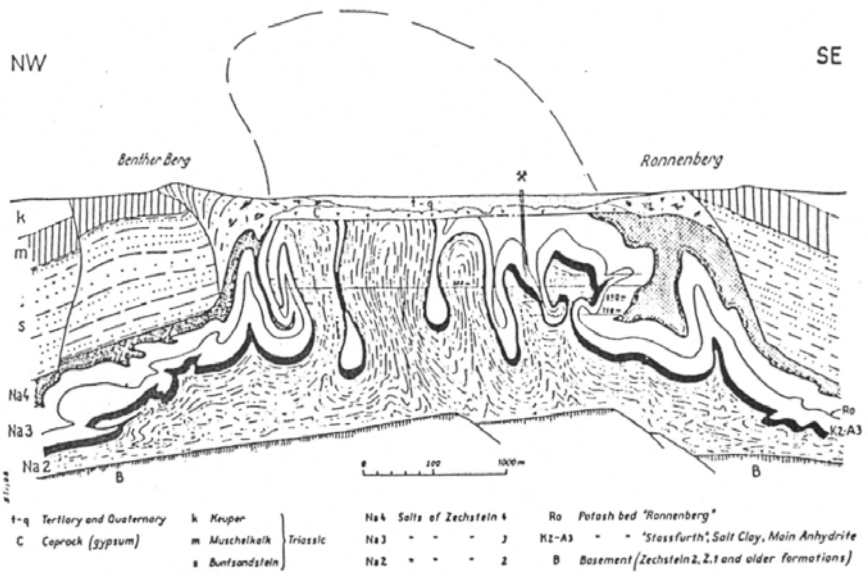
Zuidwending salt dome



Simplified geological model



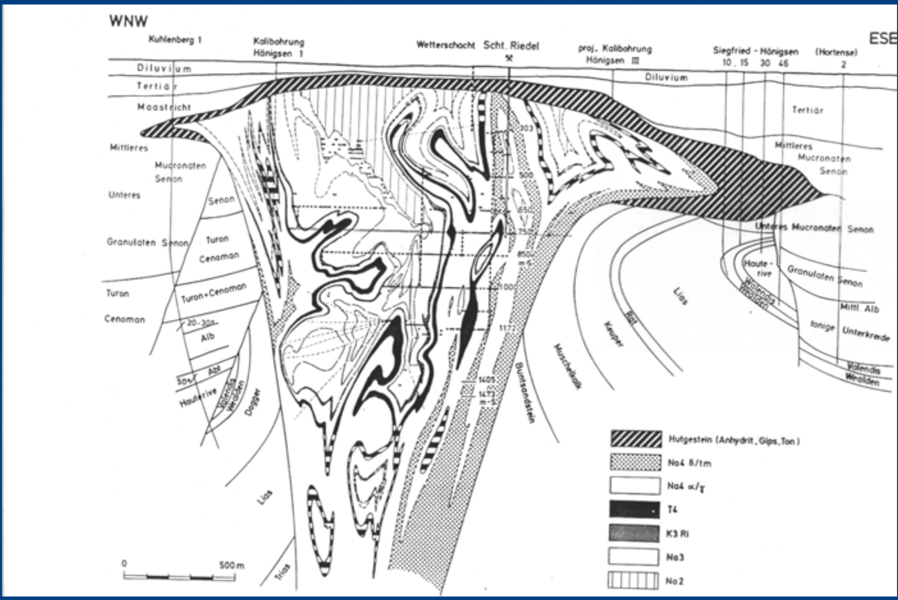
But, more complex situations can occur......



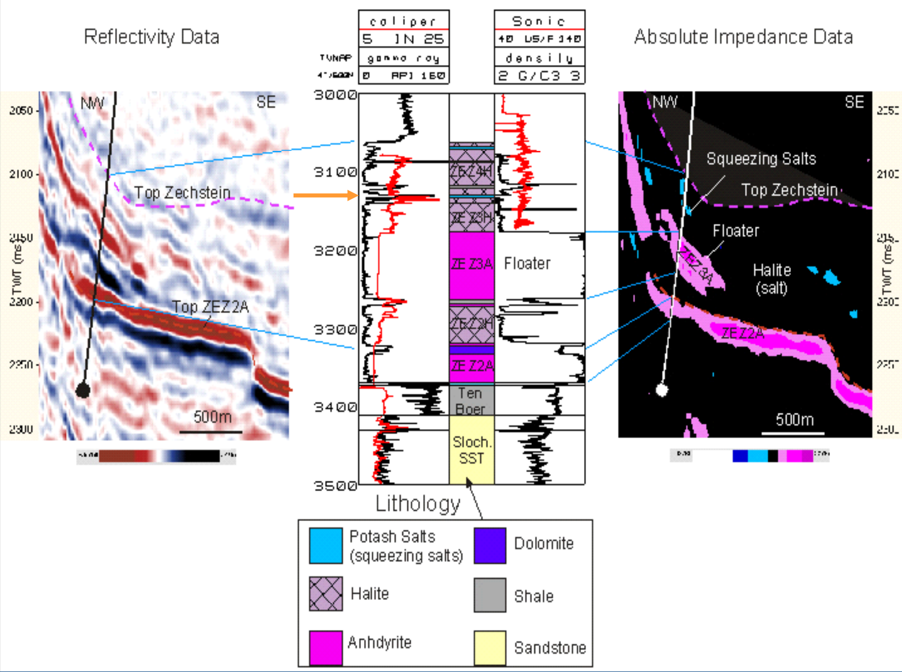
Cross-section of the salt dome of Benthe/Hanover.

Richter-Bernburg, 1972

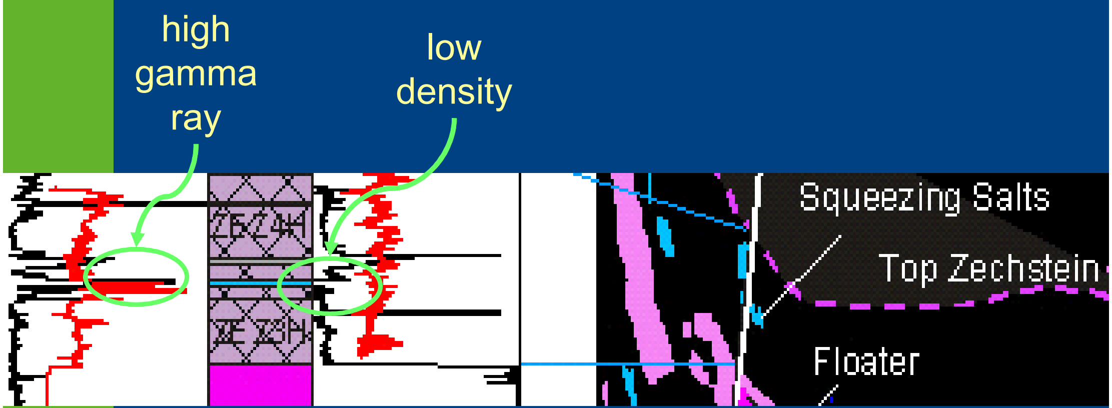
or worse....



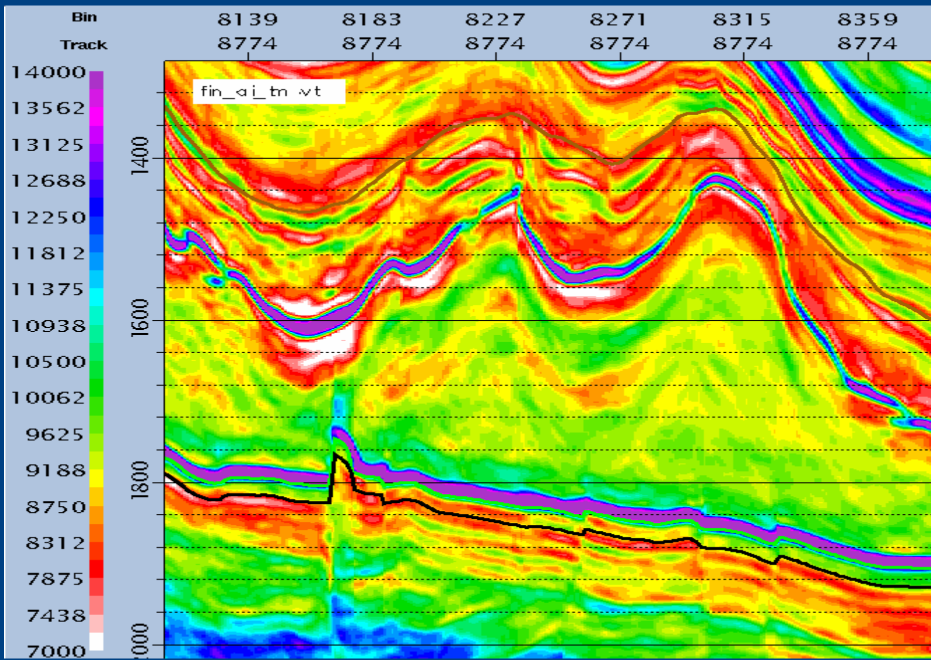
Seismic expression of squeezing salts



Correlation of seismic impedance with well log response



Acoustic impedance cube: a way to identify Floaters and Squeezing Salts



Conclusions

- ? Squeezing salt occurence is related to complex paleogeography and structuration of the Zechstein:
  - ? Squeezing salts occur in specific areas (NAM acreage):
    - ? NE Netherlands
    - ? K-blocks (and adjacent UK sector)
  - ? mapped based on well logs: gamma and density
- ? Pre-drill identification possible in seismic volumes: impedance cube
- ? Subsurface and drilling issues shared in “well trajectory sessions” by “drilling the well on seismic”.

Squeezing salts: Review of relevant salt rheologies, models of flow around borehole and a case study of salt flow around a casing

Janos Urai & Zsolt Schleder
Geologie-Endogene Dynamik, RWTH, Aachen University

Casing damage, caused by contact forces which arise from ductile creep of evaporite minerals is the final result of a complex series of processes. These usually start with a non-gage hole due washouts by a non-saturated drilling mud, or by other operational parameters. Differences in mud pressure and in-situ stress in the evaporites then leed to creep, and may result in unequal loading of the casing. Depending on the properties of the casing this may or may not lead to significant damage. A good understanding of the creep of evaporites around wellbores is one of the prerequisites of preventing squeezing salt problems.

The first part of this contribution presents results of an ongoing review of the creep properties of evaporite minerals. Besides the large differences in thermally activated creep properties of the pure phases such as Halite, Carnallite and Bischofite, there are a number of additional important parameters caused by imputities distributed over a wide range of length scales. Our database will be used to predict creep properties of evaporites from parameters observable during drilling, such as cuttings (composition, microstructure) and wireline logs (distribution of lithologies, folding). These data are then used in nonlinear finite element models to calculate the movement of the wellbore wall over time and the evolution of stress in the casing.

The second part of the presentation gives a brief overview of a case in a middle East well, where the cement around the casing provided incomplete sealing and hydrocarbons were fpound to migrate upwards in this annulus. Predictions of evaporite creep led to a decision to postpone a workower and observe the well, to see if salt creep may seal this annulus over time. Over a period of several months the rate of flow through the annulus indeed showed a stepwise decrease, demonstrating creep processes over time can lead to re-sealing.

Squeezing Salts:

review of relevant salt rheologies, models of flow around borehole and an interesting case study

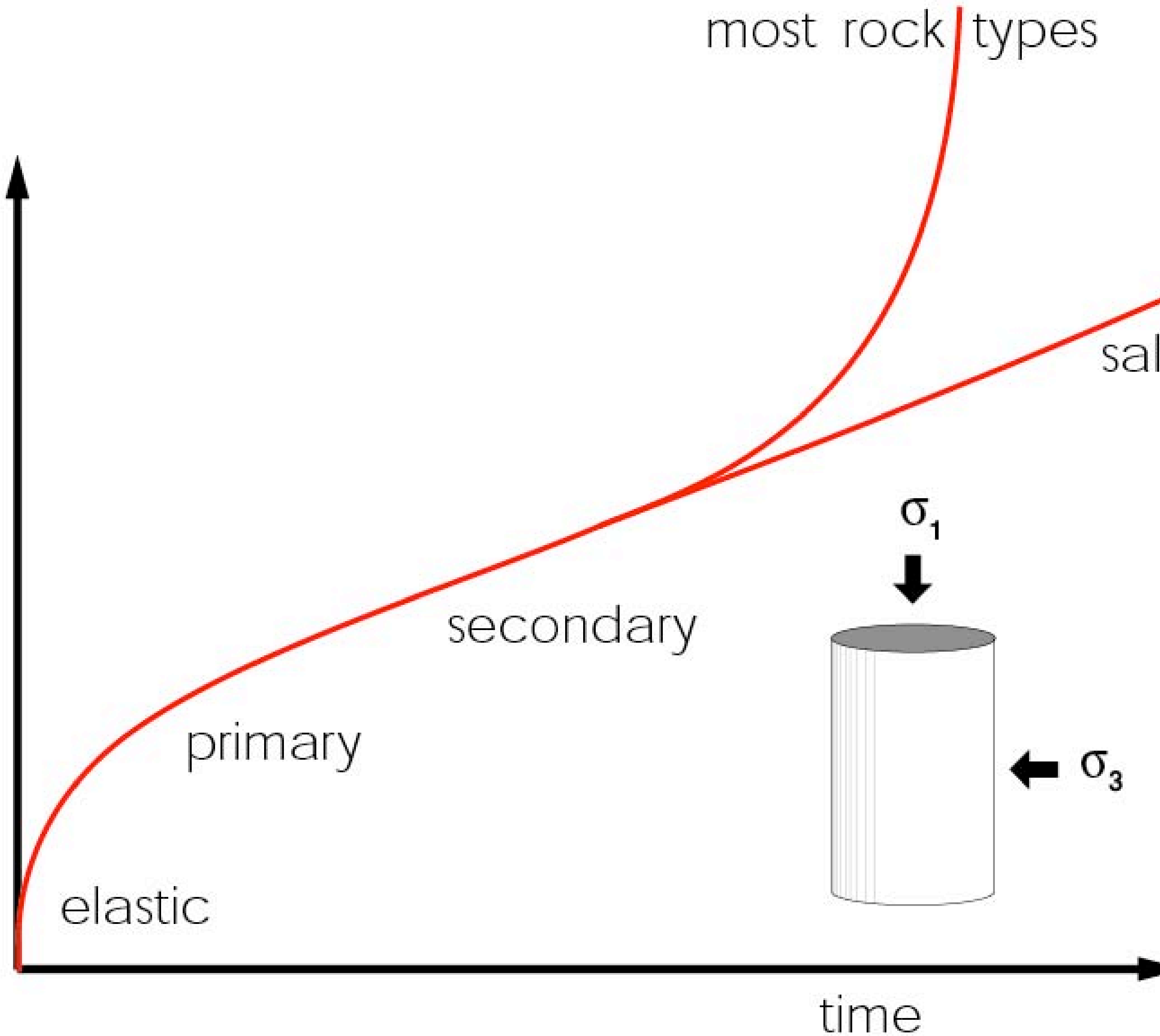
Janos L. Urai, Zsolt Schleder

Geologie-Endogene Dynamik, RWTH Aachen University |www.ged.rwth-aachen.de|

Wouter van der Zee

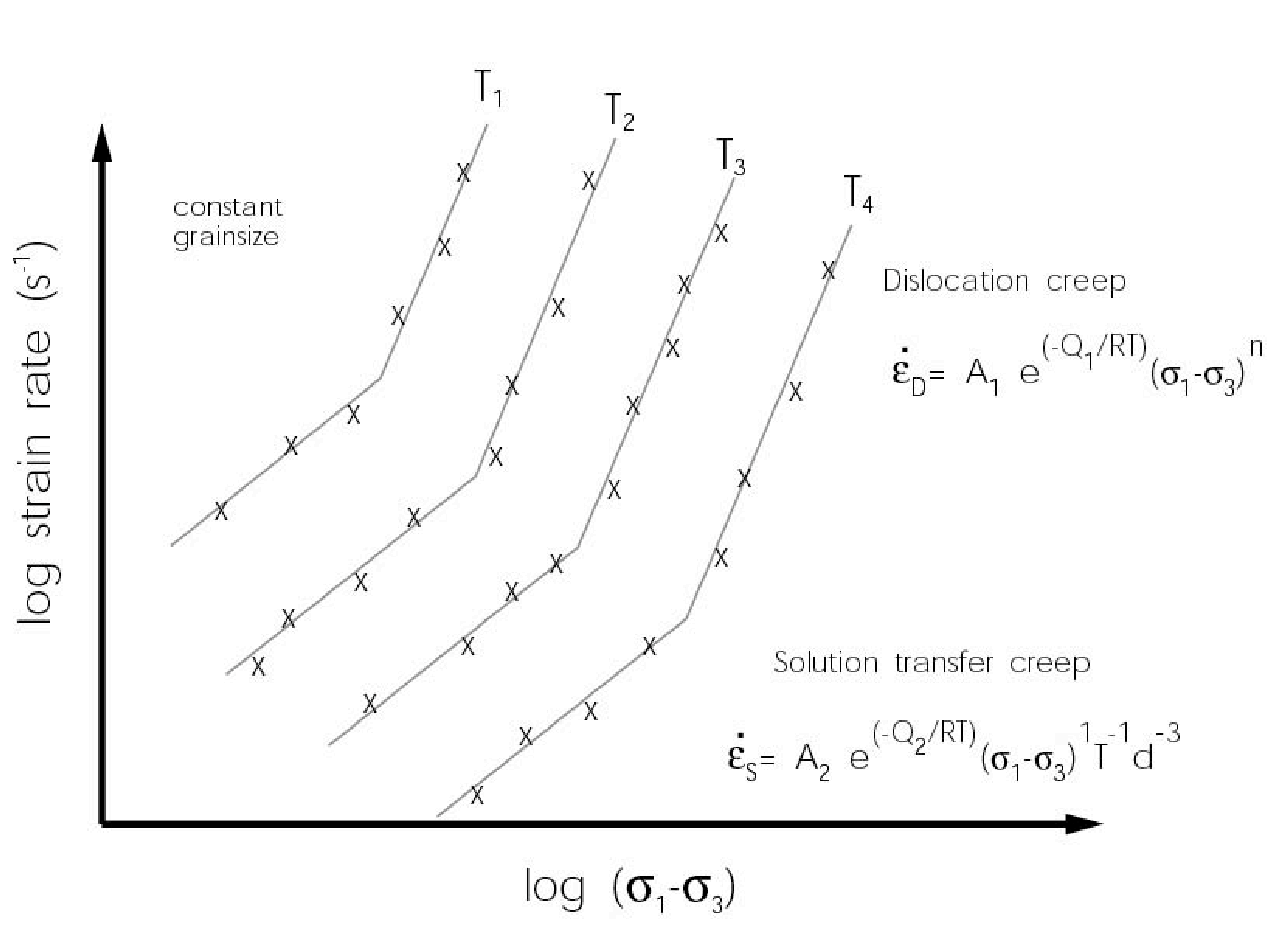
Geomechanics International, Mainz |www.geomi.com|

Ductile deformation of salt

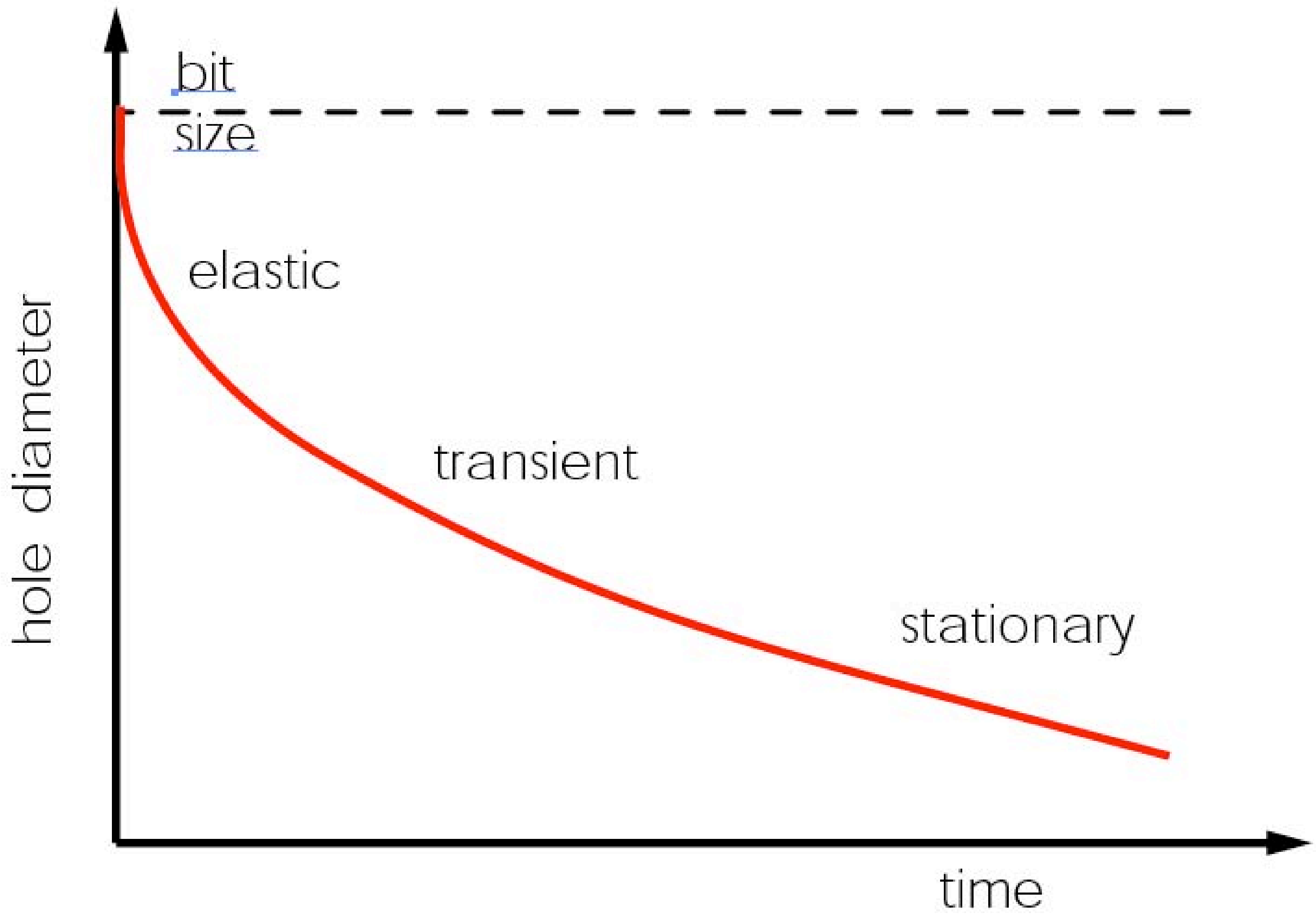


pictures: BGR

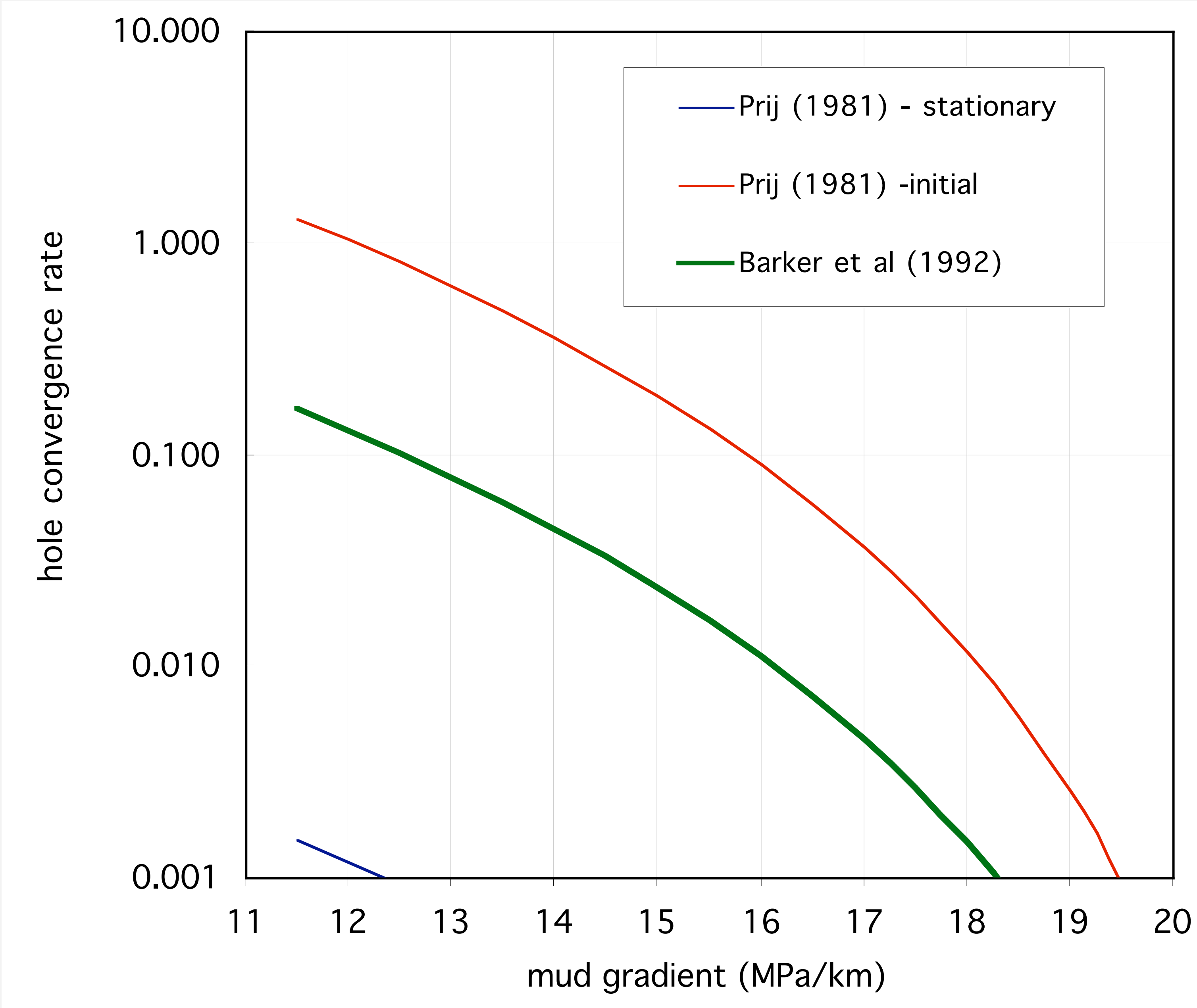
Power law creep rheology



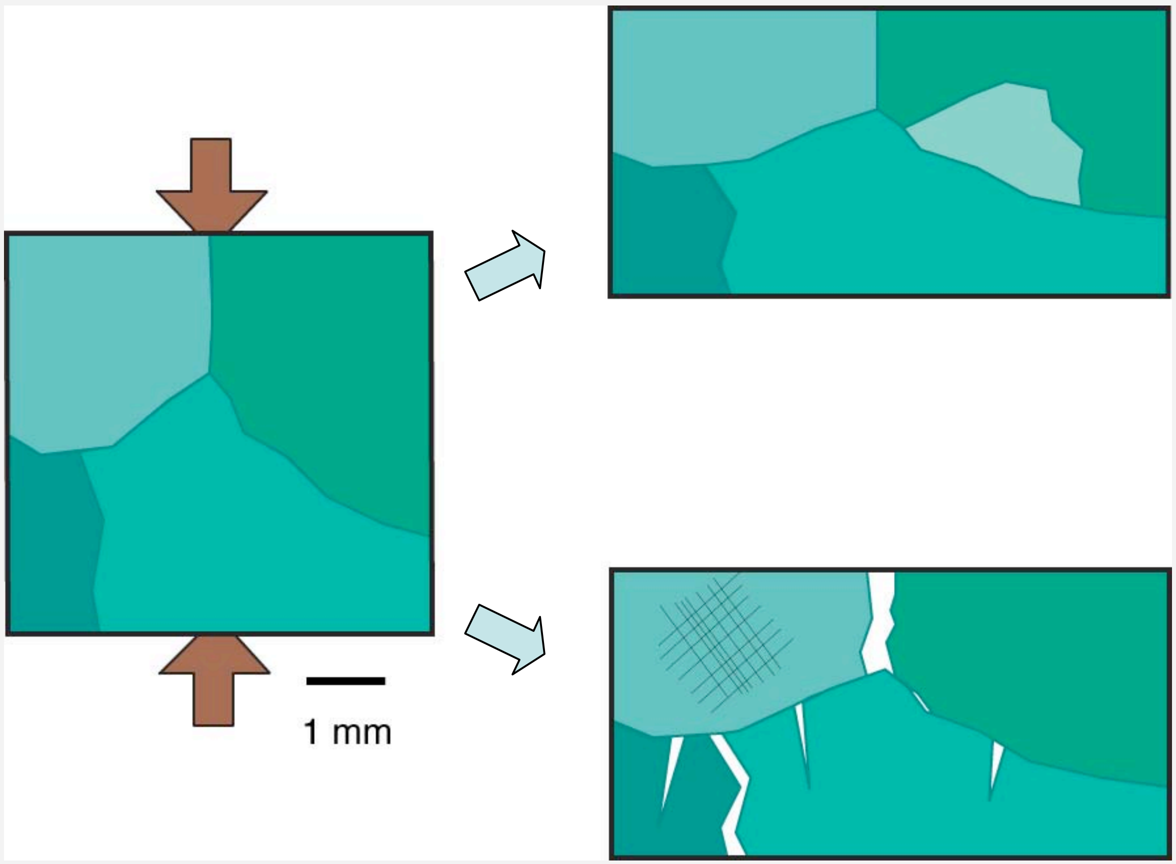
Creep closure of borehole in salt



Analytical estimates of hole closure rate in salt



Deformation mechanisms in Evaporites



fully ductile
porosity and
permeability remains
near zero
crystal plasticity
and dynamic
recrystallization

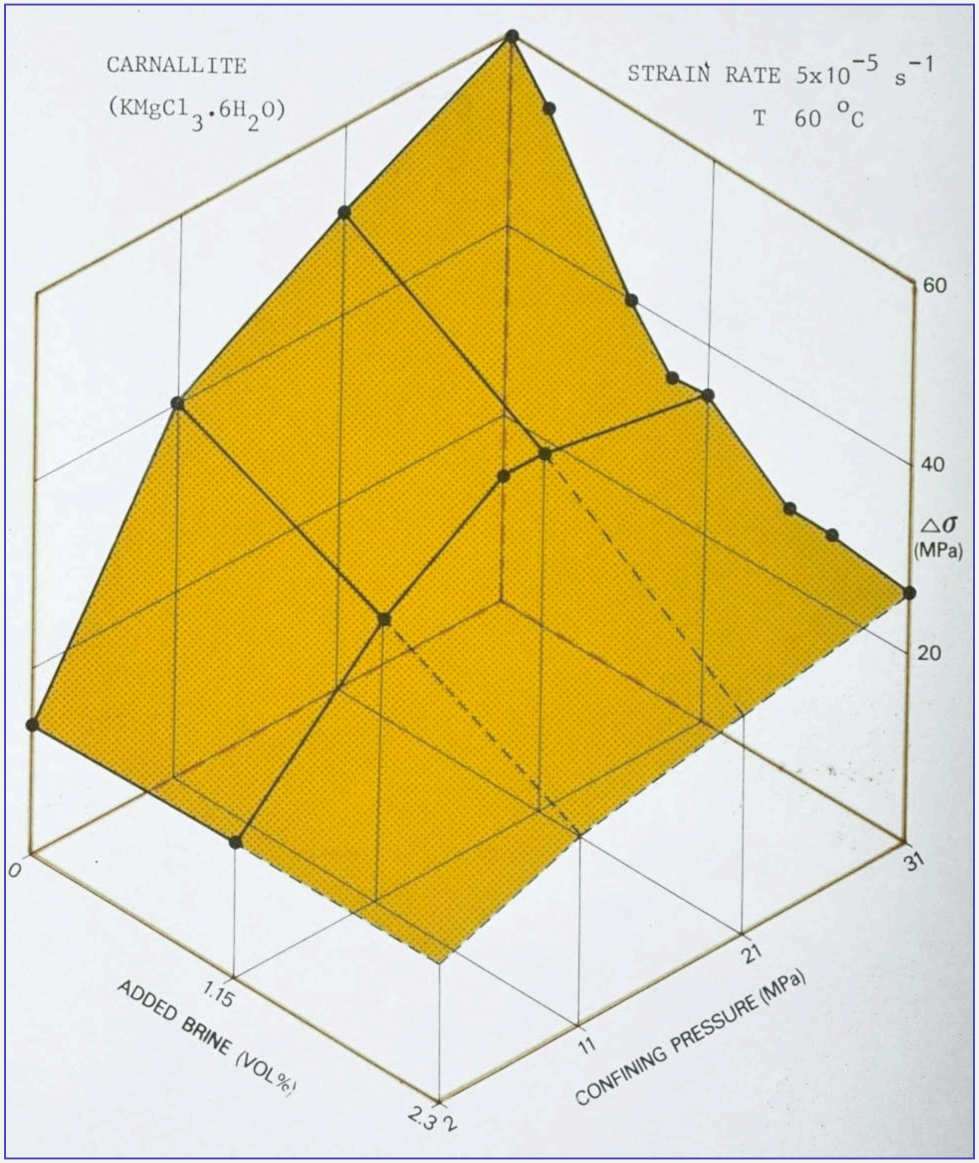
occurs under most
conditions in nature

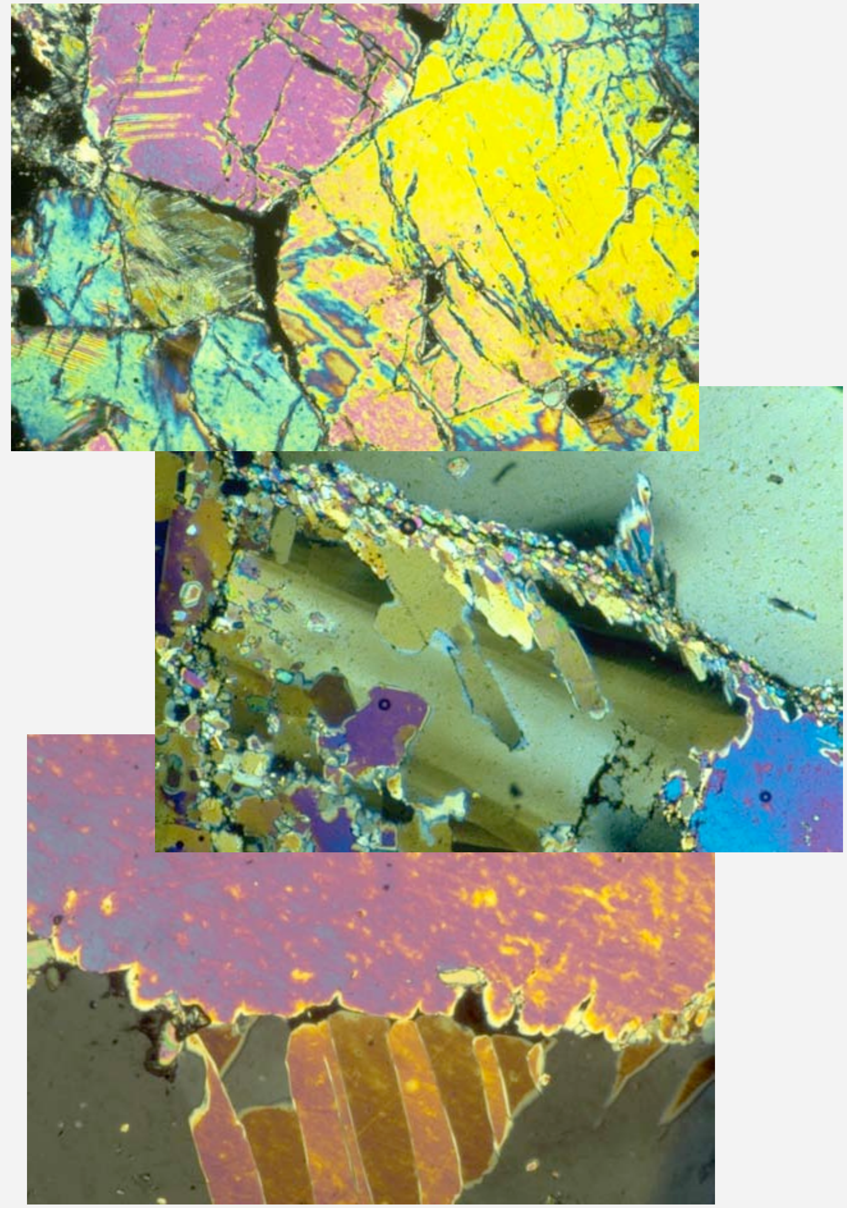
microcracking and
dilatancy
porosity and
permeability increase

in nature
only under near-zero
effective stress

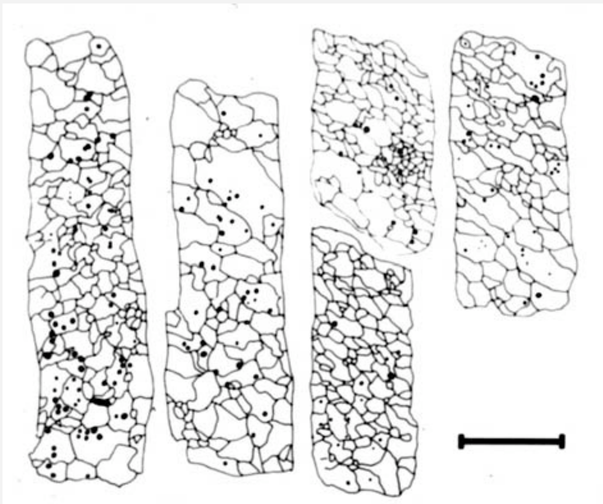
Asse Trümmercarnallit

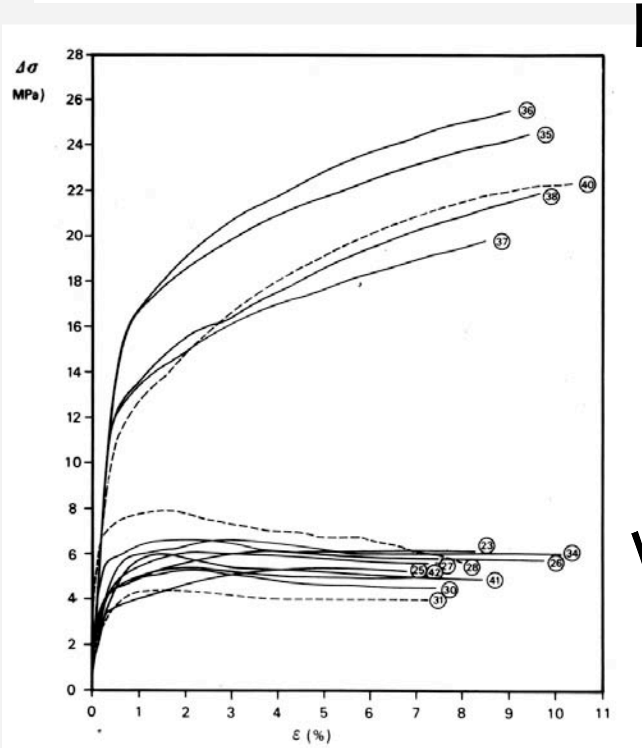
Carnallite triaxial data



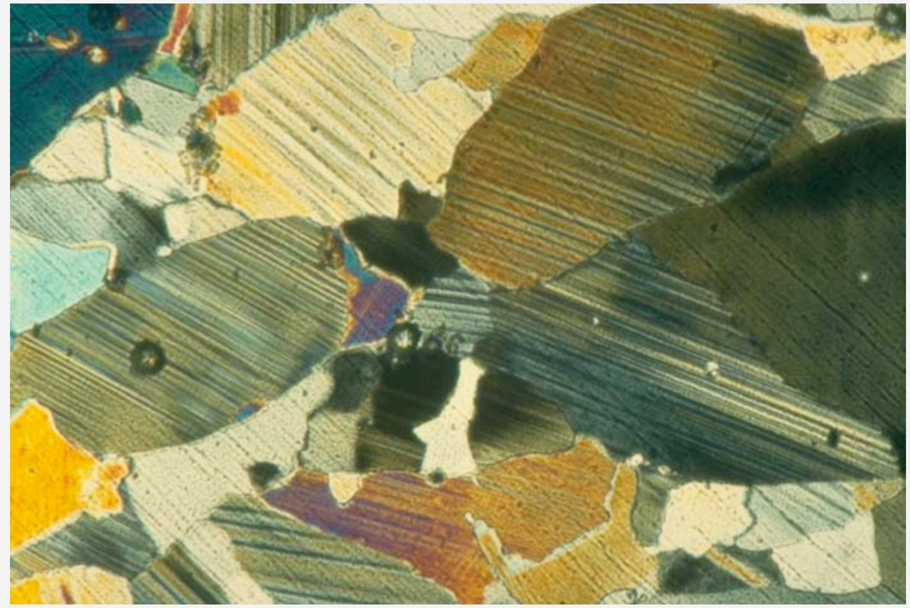


Bischofite wet and dry

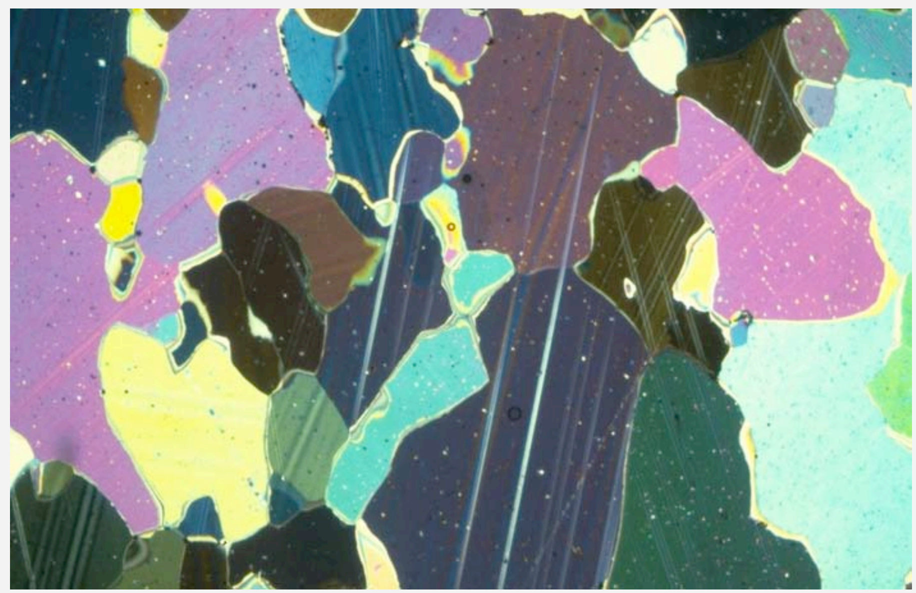




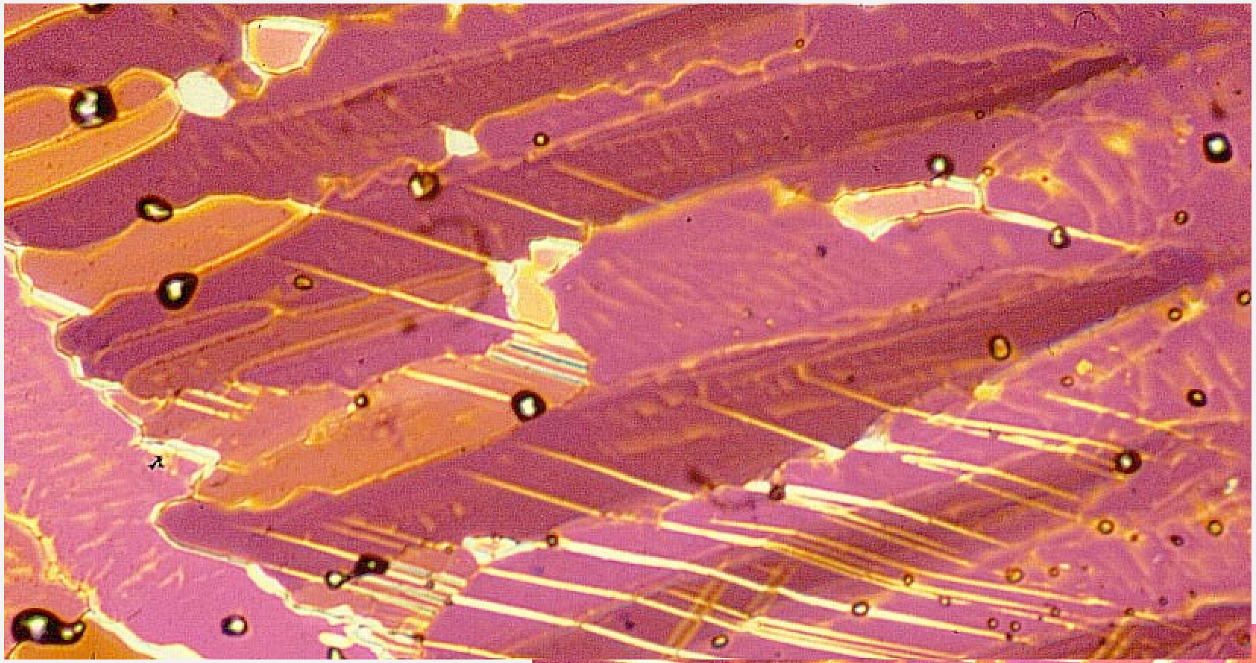
Dry

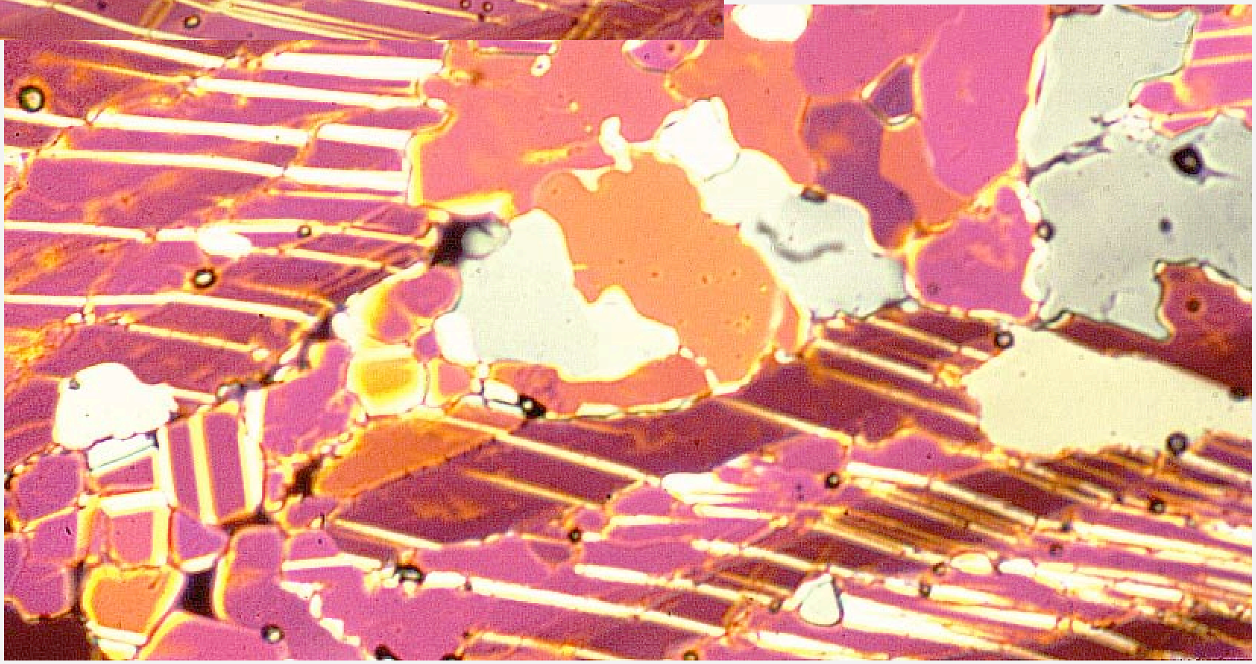


Wet

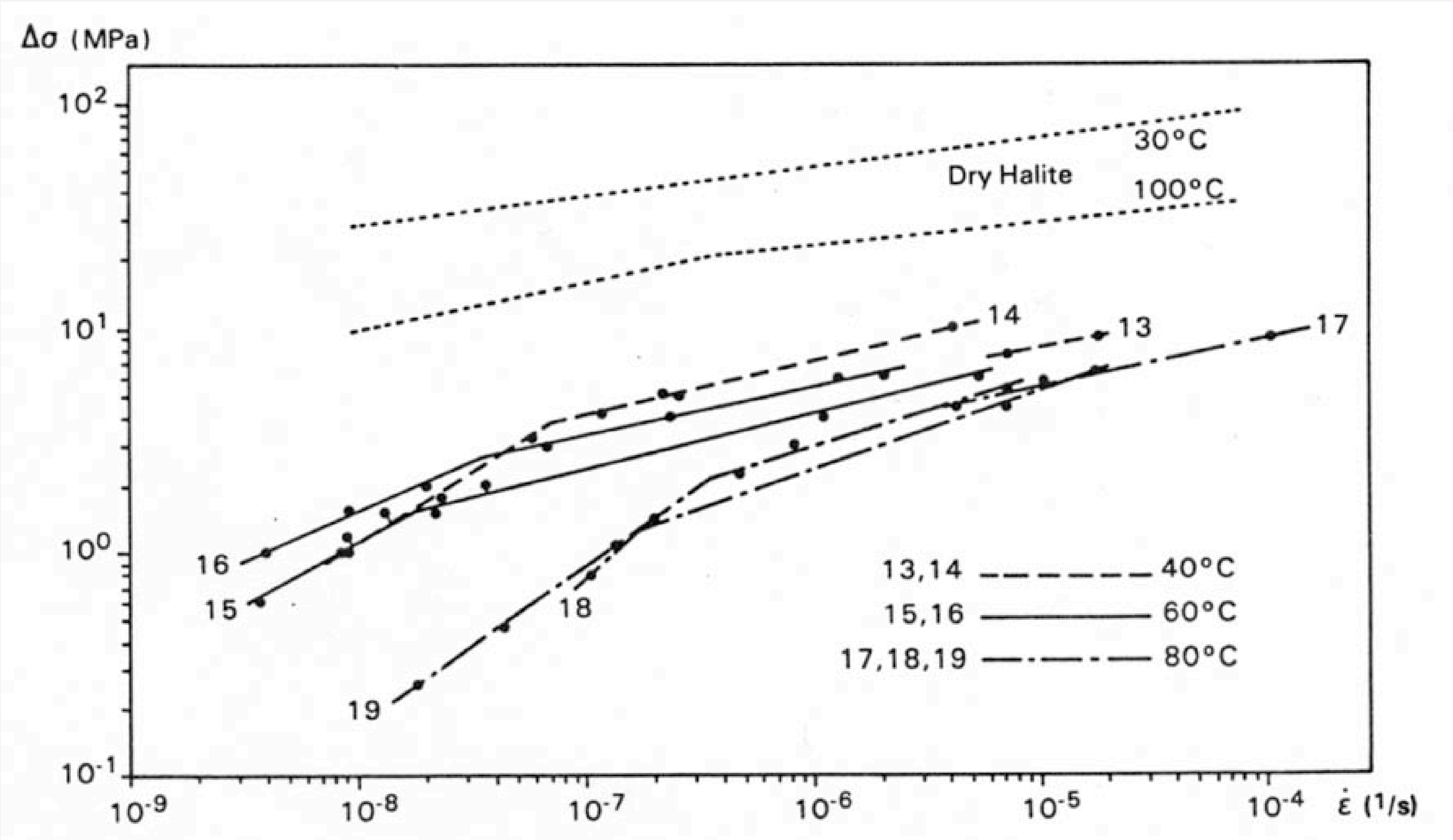


Bischofite Microstructure Evolution





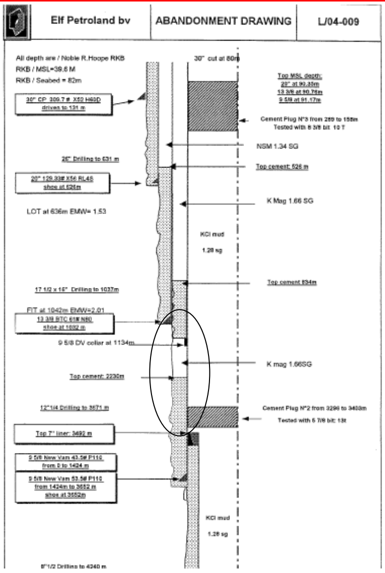
Rheology of Bischofite



L4-9 Casing collapse risk assessment

Atef Onaisi
Total

Current well architecture



L4-9

- Exploration vertical well
- Drilled and abondoned in 1999
- Casing 9 5/8" entirely in the salt,
- Cemented intervals
  - 1037m-1134m
  - 2230m to TD
- Open hole (mud 1.66 SG/Kmag)
  - 1134m to 2230 m

Casing collpase study

- **TEPN plans to convert L4-9 into a producer**
- **This will require re-entering the well**
- **Important to check if the casing 9 5/8" has resisted to collapse since 1999, in both cemented and open hole intervals**

Collapse under uniform salt loading

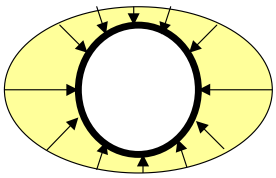
- Normal casing resistance to collapse
  - 87.4 MPa @ 150°C
  - 96.1 MPa @ 20°C

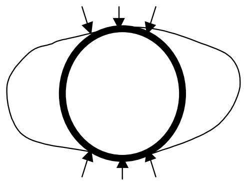
Depth	Salt Pressure assuming 2.5 SG lithostatic gradient in the salt
m	MPa
1134	27,79
1682	41,23
2230	54,66
3492	85,59

No risk of collapse under uniform salt loading

Mechanisms of casing collapse in the salt (1)

- **The risk of collapse is related to anisotropic or sector loading during salt creep or due to casing shear**

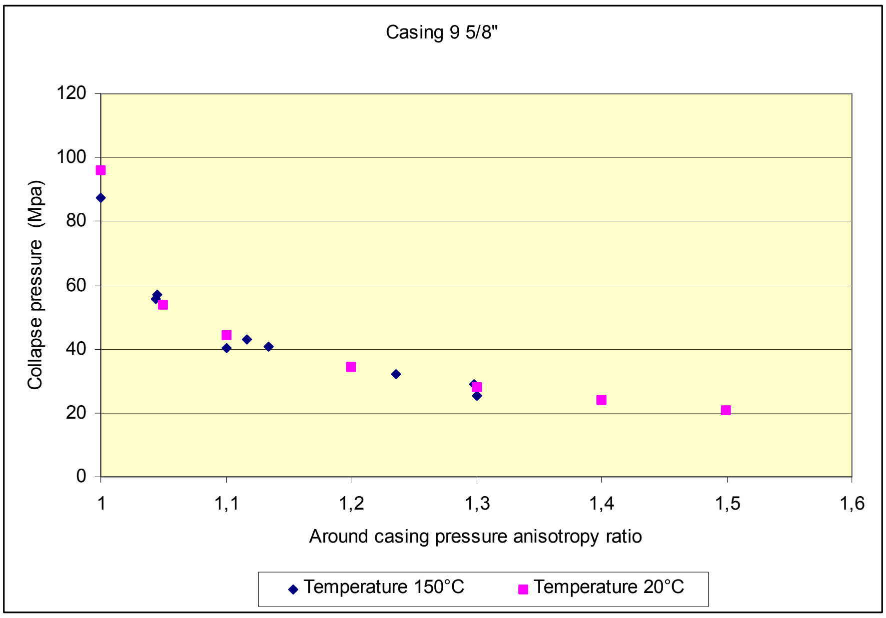

Anisotropic load


Sector load

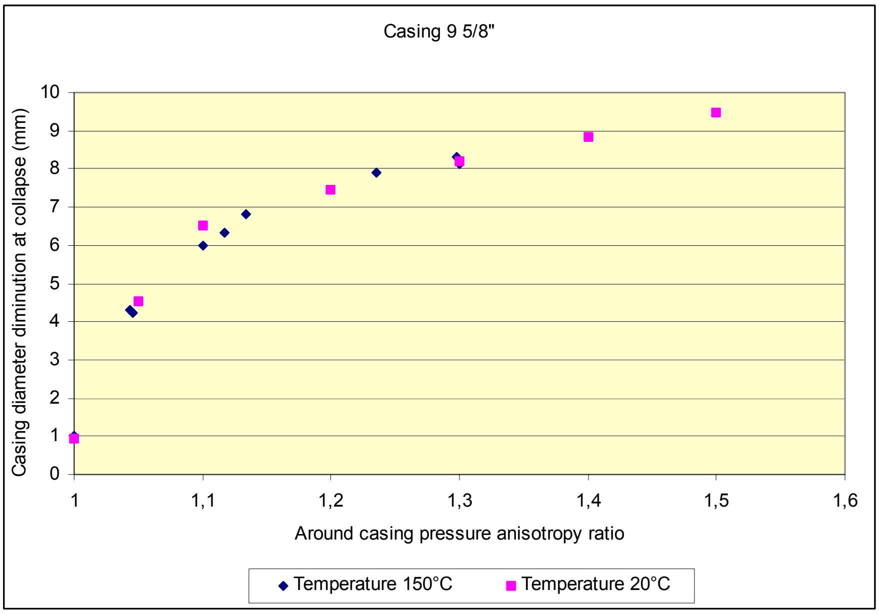
- Sector or anisotropic loading : the salt loads the casing more rapidly in one preferential direction
  - Open hole : the well geometry is not circular
  - Cemented well : the cementation is not perfect

- Casing shear might occur if the well crosses a zone of high shear strain gradients such as the interfaces between salt and other hard rocks. Casing shear might occurs inside a salt body if hard rock stringers are trapped inside the salt

Collapse under non uniform load

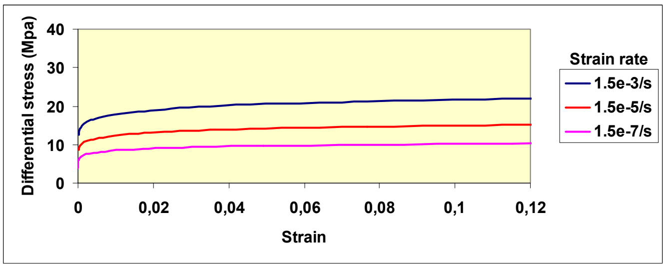


Casing deformation under non uniform load



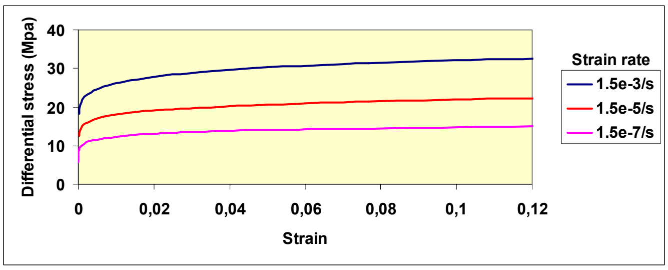
Salt creep rate

Fast creep A=1.2e-10

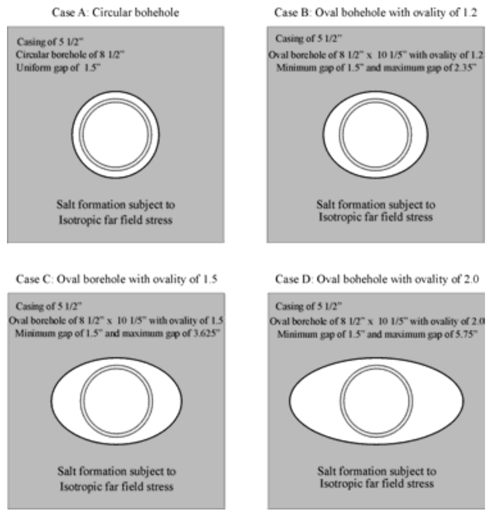


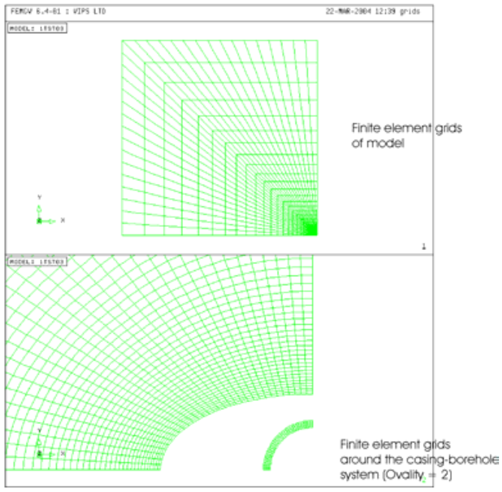
$\varepsilon = A\ \sigma^a\ t^b$

Slow creep A=1.2e-11

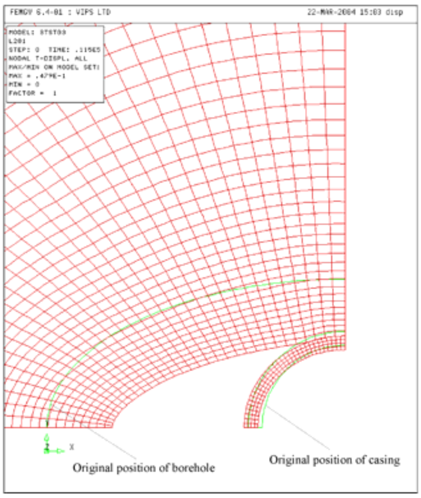


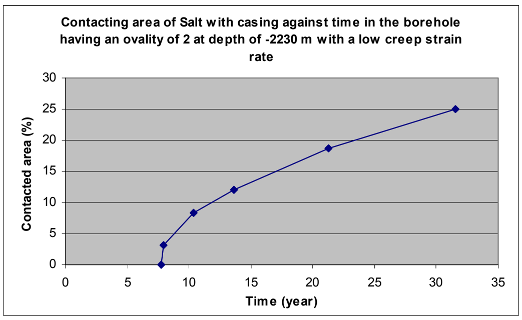
Creep simulations : open hole interval





Example of calculation of contact area versus time



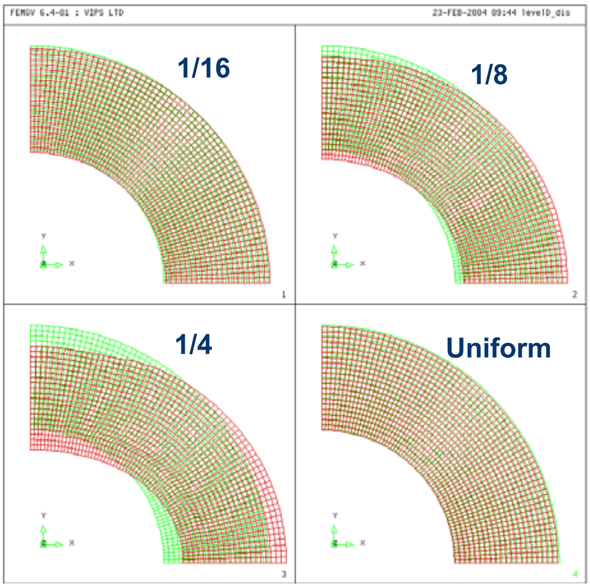


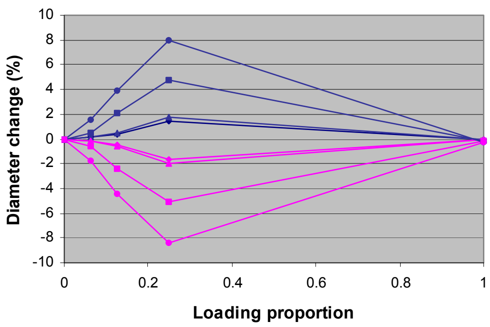
Contacting time at 2230 mTVD

Depth	Salt creep model	Ovality of the original borehole	Contacting time
2230 m (bottom of non-cemented interval)	Slow	1	Contact in 45.9 years
		1.2	Contact in 29.3 years
		1.5	Contact in 17.5 years
		2	Contact in 8.1 years
	Fast	1	Contact in 0.47 years
		1.2	Contact in 0.3 years
		1.5	Contact in 0.2 years
		2	Contact in 0.1 years

Cemented intervals : casing deformation versus contacted area and depth

2230 m





Summary of results

- **If the salt loading is uniform, there is no risk of collapse in both cemented and open hole intervals**
- **If the salt load is not uniform**
  - **Open hole interval**
    - If the mud was not injected, the creep stops very rapidly
    - If the mud was injected
      - Fast creep

        The salt contact the casing in less than 0.5 year

        The risk of collapse is very high
      - Slow creep

        It takes the salt more than 8 years to contact the casing

        The casing should be OK since abandonment in 1999
  - **Cemented interval**
    - Casing deformation depends on the width of contacted area
    - The cement does not protect significantly the casing
    - High risk of collapse if loading non-uniform because the salt is in contact with the casing from the start

Conclusions

- **Salt creep rate is very important for evaluating the timing of possible collapse**
- **In cemented intervals, the risk of collapse might be very high if the cement is not perfect because the salt might apply sector loading on the casing very quickly**
- **In non cemented intervals, there is always a delay before collapse which depends on salt creep rate. Collapse is only possible if the annulus mud is lost by injection in the salt or by leakage**
- **Shearing might be another source of collapse but was not investigated during this study**

Report of the panel discussion

The workshop was completed by a panel discussion, covering:

i) *Problem definition*

(with emphasis on technical and commercial risks in drilling)

ii) *Tackling the problem*

(to understand, predict, prevent, mitigate)

iii) *Recommendations*

(Best Practices, follow up)

Below a summary of the discussion is given.

Problem definition

What are "squeezing salts"?
"Squeezing salts" are commonly defined by lithology. In particular, they consist of the intervals within the Zechstein Group containing the evaporitic minerals carnallite ($KMgCl_3.6H_2O$) and bischofite ($MgCl_2.6H_2O$). It was briefly argued that the squeezing salts can either be identified based on their specific well log character, or alternatively on seismic profiles as a zone with a certain thickness.

What kind of technical problems do they actually cause?
The rheological properties of carnallite and (in particular) bischofite are such, that they easily 'creep' towards boreholes under the influence of stress differentials. There they may cause mechanical problems such as the 'grabbing of the drill string', hampering drilling operations and squeezing steel casings. Casing collapse has occurred not only during the drilling and completion phases of wells, but also many years after production.
Several participants emphasised the fact that the mere presence of squeezing salts does not necessarily result in mechanical problems. E.g. the internal structure (intense folding) is a factor which may or may not contribute to the squeezing character.
Anisotropy in the shape of the borehole and shearing (along the salt – non-salt interface) were also mentioned as factors which contribute to the collapse of the casing.

Where do they occur (in the Netherlands)?
Stratigraphically, squeezing salts occur in the upper parts of the Zechstein-2H, -3H en –4H, in conjunction with polyhalite marker beds, characteristic for the cyclic development of Zechstein evaporates.

NAM has performed a mapping of the occurrence of squeezing salts, based on well data from their acreage in the Netherlands (and the UK).

What safety issues are involved?

Generally, squeezing salts as such are not considered a safety issue. Nevertheless, they indirectly may contribute to a safety risk, when problems in other sections of a well occur ('mud weight game over multiple zones').

What commercial risks are involved?

Squeezing salts may cause considerable delay in drilling a well. At drilling rig rates ranging from 50.000 to 200.000 $/day this is a commercial risk, although usually within the contingent costs range for a well. Eventually, a well may be completely lost due to squeezing salts problems, a significant commercial risk in the order of millions of dollars.

Tackling the problem

Understanding the mechanisms

The rheological properties of carnallite and (in particular) bischofite are such, that they easily 'creep' towards boreholes under the influence of stress differences.

Causes / triggers

Wrong mud systems and/or long exposure of the Zechstein to the mud lead to an increased risk of drilling problems.

Ductile creep leads to contact forces from the squeezing salts on the casing.
Unequal (anisotropic, sector) loading of the casing may cause forces that exceed the casing strength and the casing collapses. Hole irregularities (washouts or ledges) may contribute to these processes.

On the longer term, poor cementation but also shear stresses due to depletion may trigger squeezing salt problems.

Predictability

Prediction starts by using regional knowledge and experience. Squeezing salt problems seem to be related to certain geological settings, although the underlying mechanisms are not well understood.

Geomechanical computer modelling may assist in choosing conditions to prevent problems during drilling. A case was reported, where the main hole had severe squeezing salts, whereas the nearby technical sidetrack, having a very similar log characteristic, showed none. This indicates the short scale in situ variability of the problem.
Research on the relationship between composition, microstructure and rheological properties is still ongoing. So far, variability in creep behaviour for the same lithology under the same temperature and stress is an order of magnitude or more.

Detection

The way squeezing salts can be detected depends on the stage of a well:

a) *Well planning*
Seismic, linked to anhydrite marker
Low impedance in an inverted AI cube

b) *Drilling*
Mg content monitoring

c) *Logging*

Noisy, high gamma ray (GR) log reading are considered as a warning.
Preferably, a combination of logs is used (e.g. GR + Sonic + caliper) to detect squeezing salt intervals.
Carnallite is characterized by high GR and low density readings.
Bischofite seems hard to detect directly from logs

Modelling techniques such as Global (e.g. applied by Schlumberger in Zuidwending wells) and ELAN (applied e.g. by TNO-NITG on Barradeel wells) allow for determining volume fractions of minerals.

Prevention & control

An obvious way to prevent squeezing salt problems is not to drill through them at all. However, given the rather large spread of occurrence in some areas, this rarely is a feasible option. Only in salt dome structures, the squeezing salts have moved to the sides of the structure and drilling through the centre should give less problems regarding squeezing salts.

When drilling, problems can be prevented by applying optimized mud systems, adjust mud weight and not having a too long open hole section for too long a time.
Both oil based (Low Toxic Oil Based mud) and water based (Mg-K mix) mud systems are successfully applied. Oil based muds prevent washout of salts. The Mg-K muds can adapt to solubility of either of the components coming from the mobile salts and thus stabilize.

Underreaming over the nominal diameter is used as a preventive measure against getting stuck will the drill string.

Setting Heavy-duty or MUST casing over mobile salt sections has proven to be a quite reliable measure for preventing squeezing salts problems. Costs are relatively low (65,000 Euro for 500 meter section) when compared to the commercial risks of delay in drilling or loss of a well (see above); sufficient supply of this casing material should be available at the drilling rig in advance.
Some operators report, that as a standard practice they will set heavy duty casing over the full salt section and not try to only selectively set this more expensive casing.
Still, cases have been reported, where even heavy duty casing did collapse, most likely due to point contacts of the ductile creeping salts with the casing, creating differential stresses on the casing that exceed the nominal rating.

Remedial actions

In general, when squeezing salts have been set in motion towards a borehole, there seems to be no way to stop them. Therefore, strong emphasis is to be on prevention rather than on mitigation.

Recommendations

Best Practices

When preventing problems with squeezing salts, strong emphasis is on the well planning stage.

First of all, practical experience in the area of interest is a valuable asset to use in well planning. This experience usually is in the heads of some experts, but should preferably be made accessible in a database system wherever possible.

Nowadays it has become standard practice to do well planning in an open-minded interaction between geoscience and drilling staff ('multidisciplinary well trajectory sessions'). Both the well operator and the drilling contractor should be represented.

The well planning and drilling supervision can be assisted by techniques such as:

- integrated workflows;
- decision trees (various scenario's and actions to be taken);
- 3D caves for visualization and integrated planning;
- geomechanical computer simulations.

Finally, a good understanding of creep processes in salts is required.

Follow up

A Joint Industry Project (JIP) might be identified with the objective of compiling the relevant information (maps, geomechanical properties) in a GIS-environment and make it available for all stakeholders.

It also was proposed to prepare a 'guide' of best practices for drilling in squeezing salts environments.

Finally, it was proposed to consider organising similar workshop on related subjects, such as e.g. drilling hazards from anhydrite floaters in the Zechstein.

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