Can we predict Salt Drilling Incidents?

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workshop Zechstein drilling 21.5.2014

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Content:

- Introduction
- Salt is different
- Seismic clues
- Learnings from the past
- Conclusions

EBN Well Review analysis

Operational performance → O

Reservoir performance → R

well	operator	type	Target fmt	Summarized results	O	R
		E	Volprie sst.	water bearing; P&A		
		E	ROSLU	ROSLU within range; ROSLL water bearing		
		E	ROSLL	delayed due to coring & high gas levels in Volprie; logged behind casing due to obstructed WL		
		E	Z3 Carb.	Z3 is tight; Z2 has over 500 ppm H_2S; Vlieland is tight, but fraccable; SL column is small		
		E	ROSLL	small column; tight reservoir; P&A		
		E	ROSLL	severe mud losses in Volprie; high p		
		E	Bunter	small column; tight reservoir; P&A		
		E	Tersch.	reservoir within expectation range;		
		E	RO	results in low-mid case range		
		E	Bunter	total losses in Chalk; results around		
		A	Bunter	unforeseen casing mid NS; low perm		
		A	ROSLU	depleted reservoir: formation press		
		P	ROSLU	sidetracked 2X: [1] minor ST in NS. [kick off in NS; section drilled, expandable casing stuck; well suspended		
		P	ROSLU	water bearing; suspended for future sidetrack		
		P	ROSLU	results within expectation range		
		P	ROSLU	60 bar depletion; results within range		
		P	ROSLU	economic development; no H_2S produced		
		P	ROSLU	sidetracked 3X in NS; unconsolidated formation; operational issues; disturbed drilling area; plugged		n.a.

confidential

traffic-light coding:

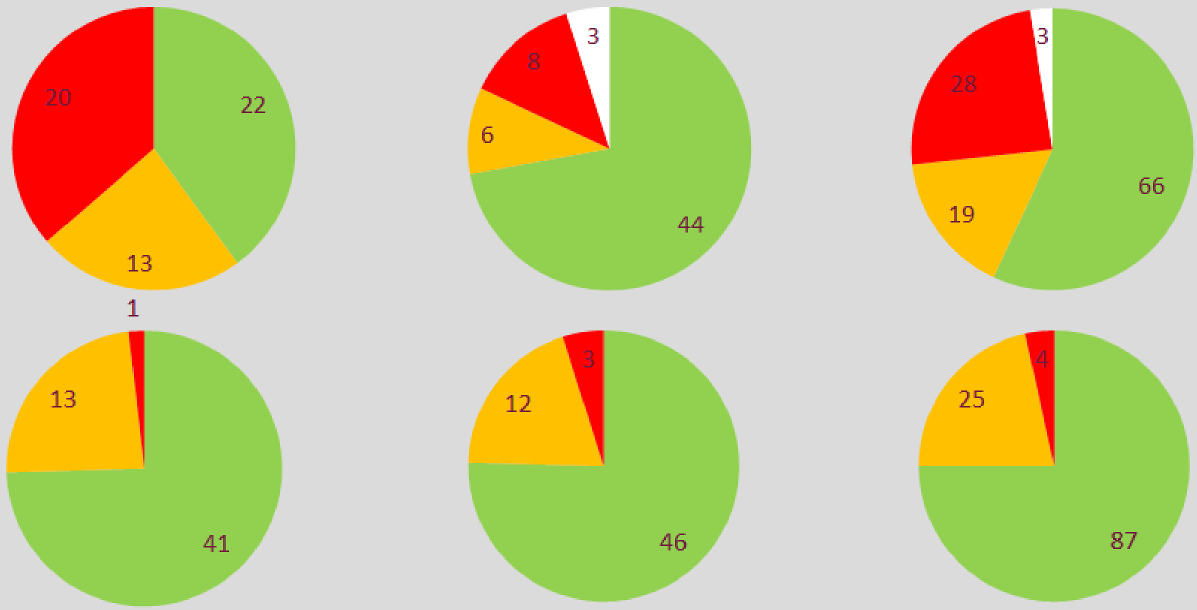
good
medium
poor

EBN statistics (116 wells; 2010-2013)

E&A | **D** | **All wells**

Reservoir

Operational



~25% of wells show massive cost overruns!

Half of these are related to geo-drilling hazards

Ref: Drilling Hazards Inventory: the Key to Safer -and Cheaper- Wells, SPE 166254 G. Hoetz et al.

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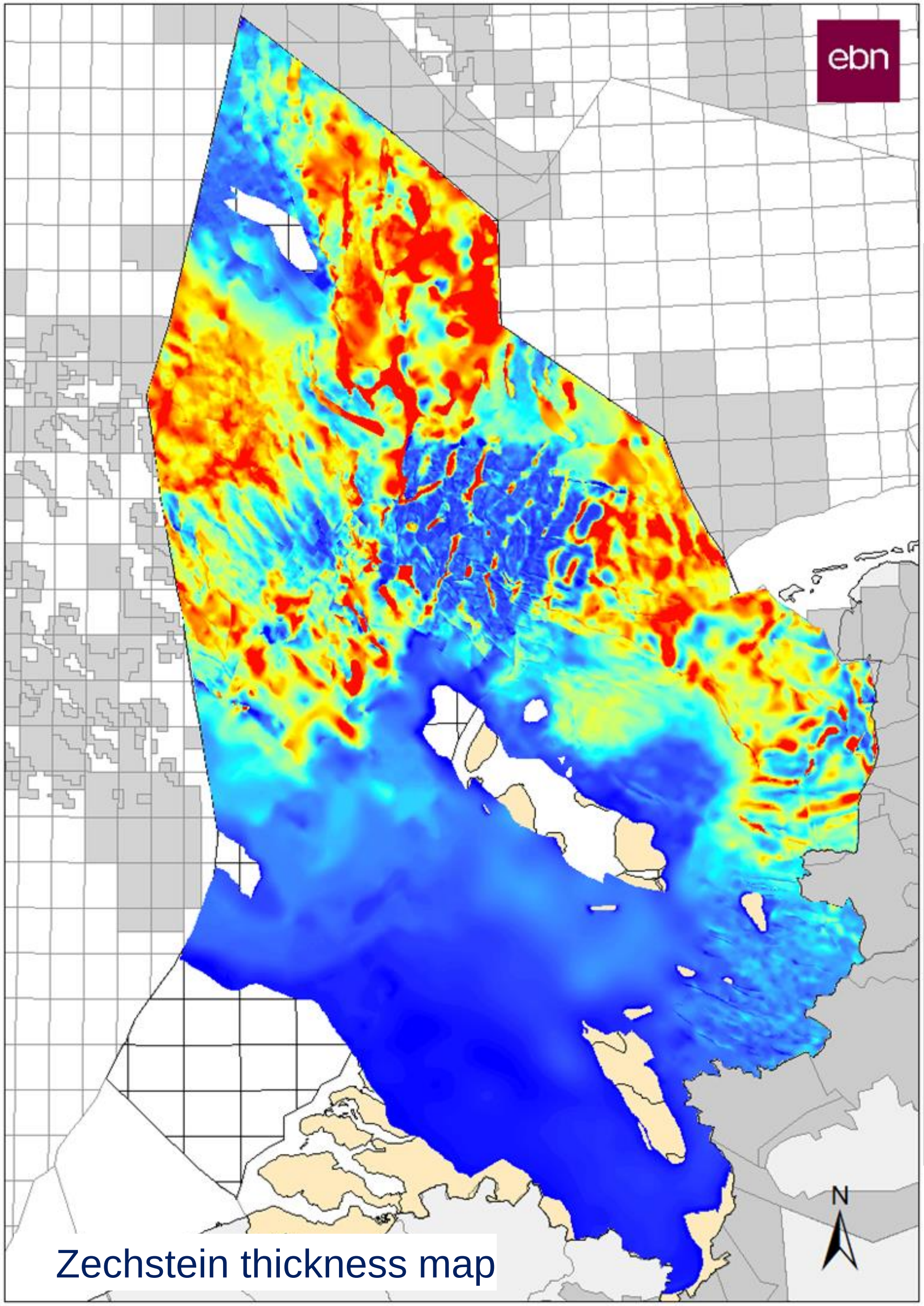
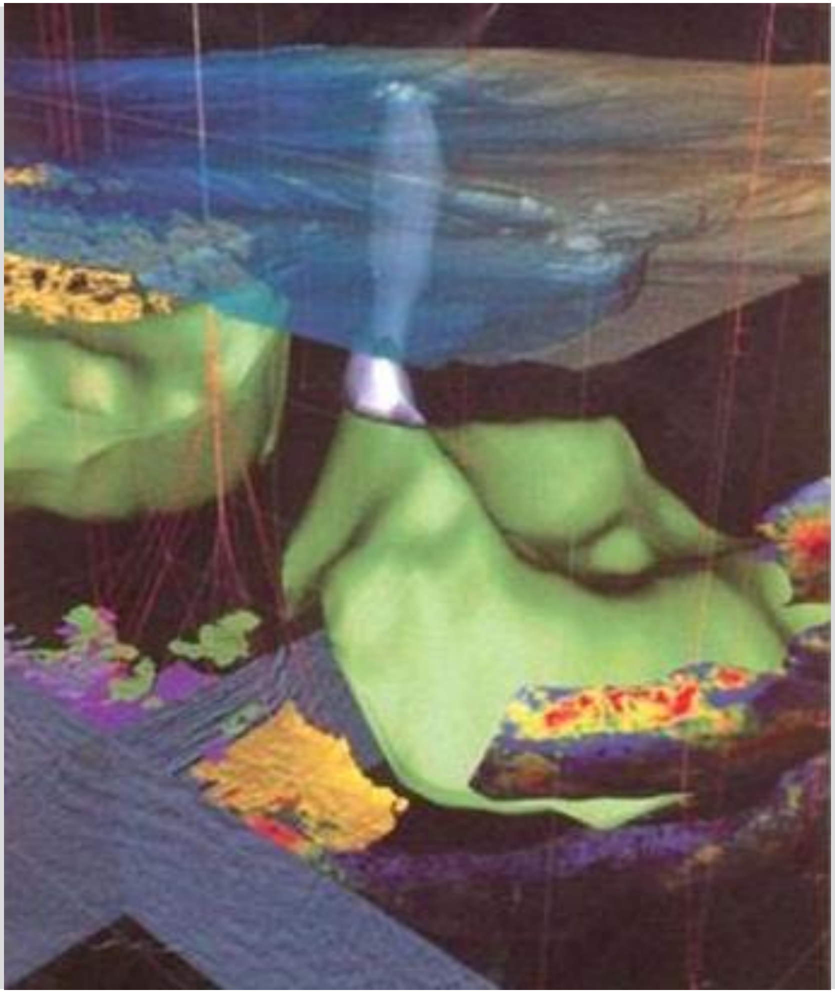
Zechstein

- lots of it
- Highly variable in thickness & composition



Zechstein thickness map

Salt is different



Three salt properties in particular determine this unique behavior: density, viscosity and solubility:

Salt density does not vary significantly with depth. Therefore, salt below a critical depth becomes less dense than other sediments more sensitive to compaction. This *gravity instability* can lead to buoyant uprising of the salt through the overlying sediments.

Salt is weaker than most other sediments. Its deformation is strongly time dependent. (*viscous creep instead of brittle deformation*).

Salt is highly soluble in water and may easily dissolve in circulating groundwater.

Ref: G. Hoetz and J. Verbeek: PESGB geophysical seminar, London 2008

3 Types of salt related damage

Stuck drillpipe

During drilling the mobile salts might enter the borehole and grab the drillpipe. Can end up in abandoning the hole and redrilling the well.

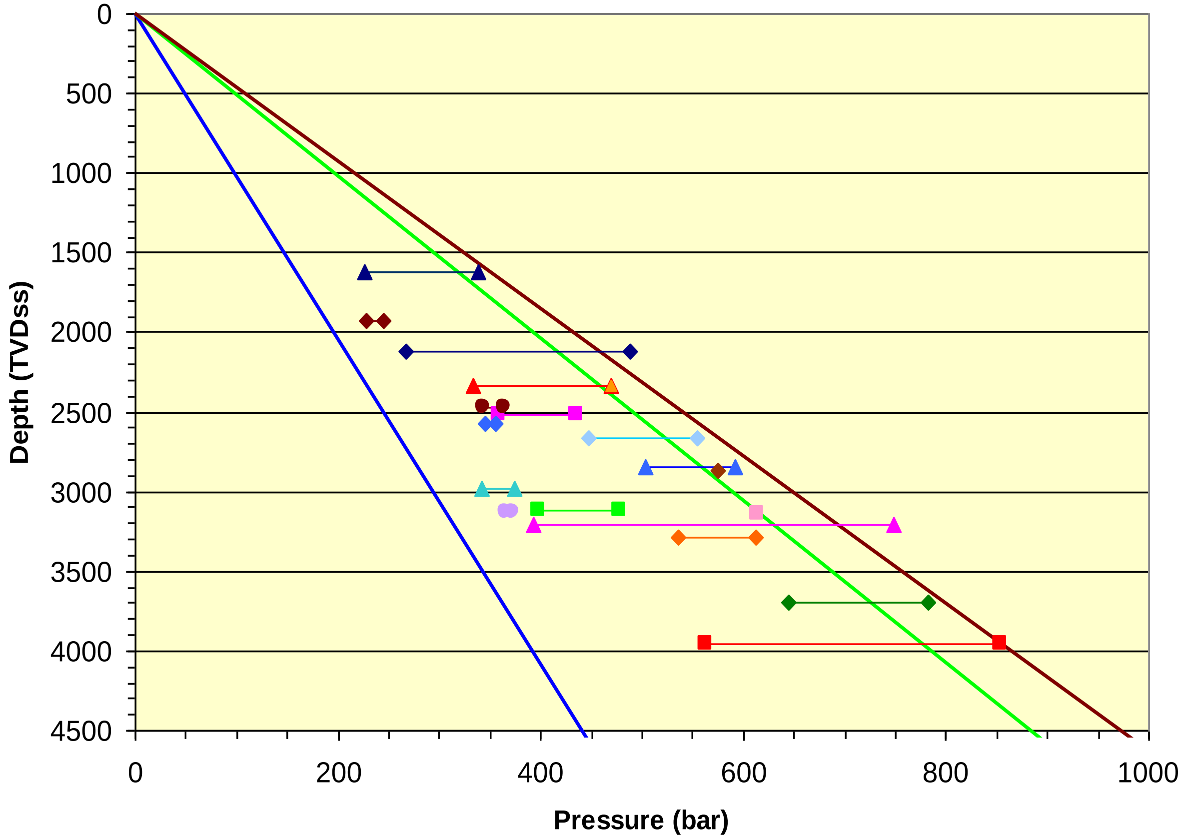
Casing collapse

After hole has been drilled and casing set successfully, later salt movements damage the pipe in such a way that the well becomes inaccessible.

High Pressures

Anomalously high pressures suddenly encountered while drilling: can result in giving up the hole. Fluid pressures in the range of 800-1000 bar have been observed (in line with the lithostatic gradient).

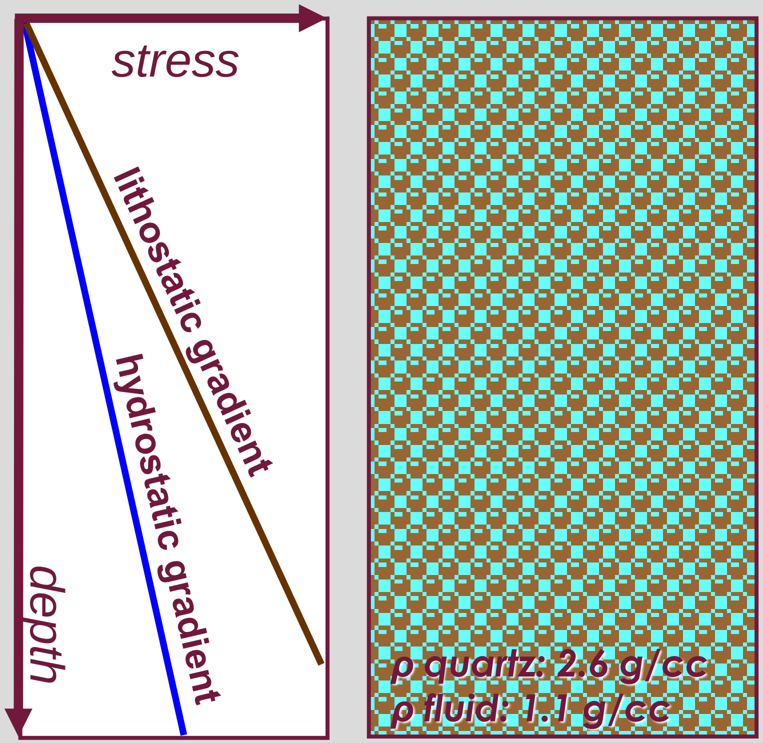
Zechstein Pressure kicks quantified



ZEZ3 raft pressures measured via mudweight

Why overpressures in salt?

Sandstone

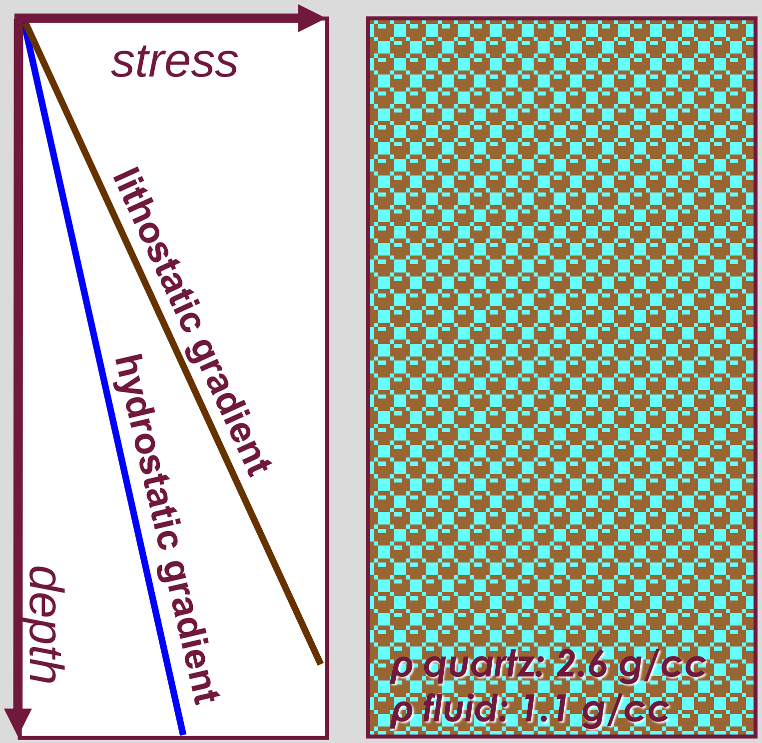


- Porosity & Permeability
- Fluid filled
- fluid gradient ≠ litho gradient
- Mudweight based on hydrostatic gradient

Ref: "*Are salt kicks predictable?* G. Hoetz et al. PESGB geophysical seminar, London 2008

Why overpressures in salt?

Sandstone



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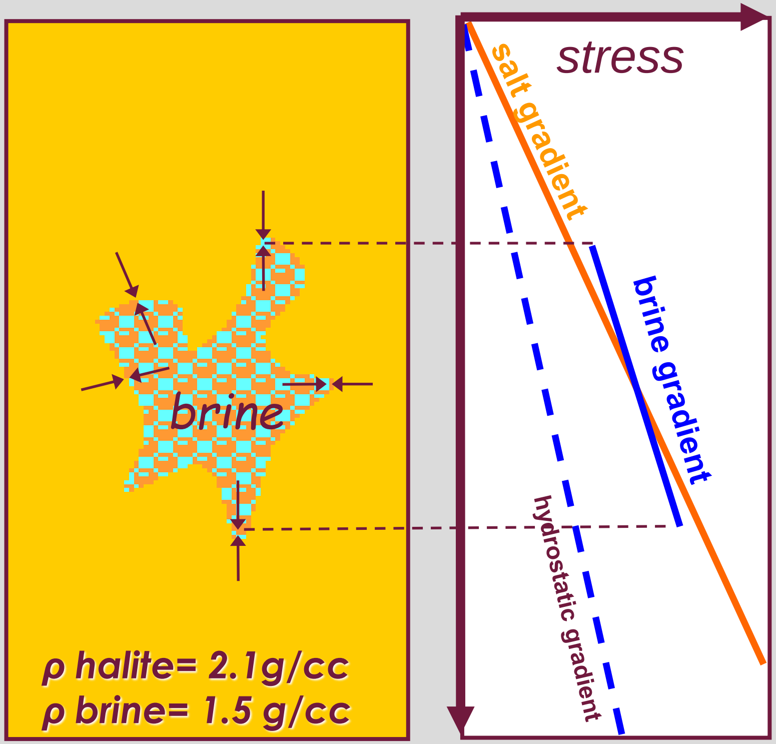
Salt

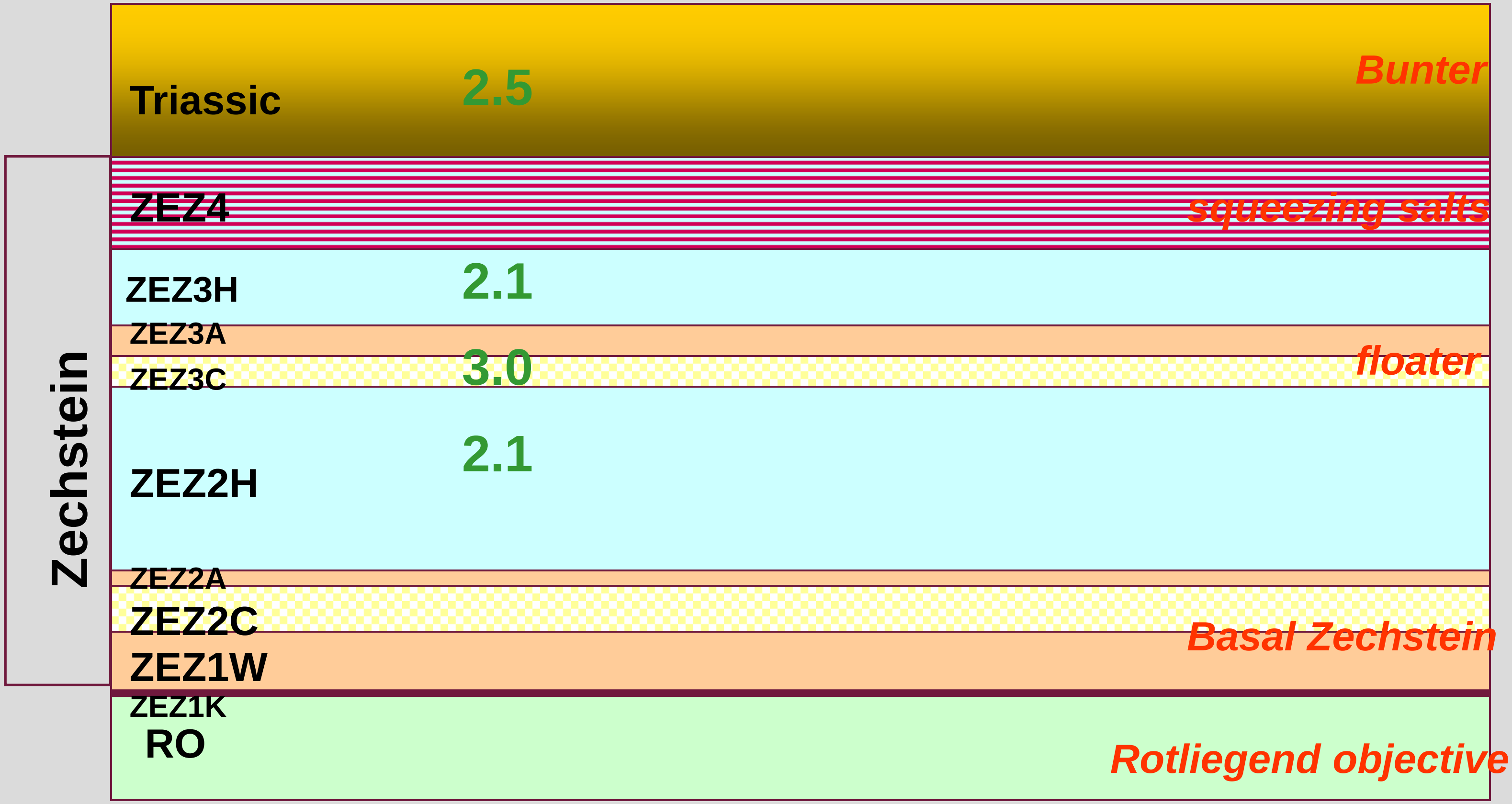


• isolated porosity (fluid filled)
• Salt is mobile
• fluid pressure ≈ litho pressure

Salt encased fluids adopt salt pressure (Pascal's principle)

Ref: "*Are salt kicks predictable?* G. Hoetz et al. PESGB geophysical seminar, London 2008

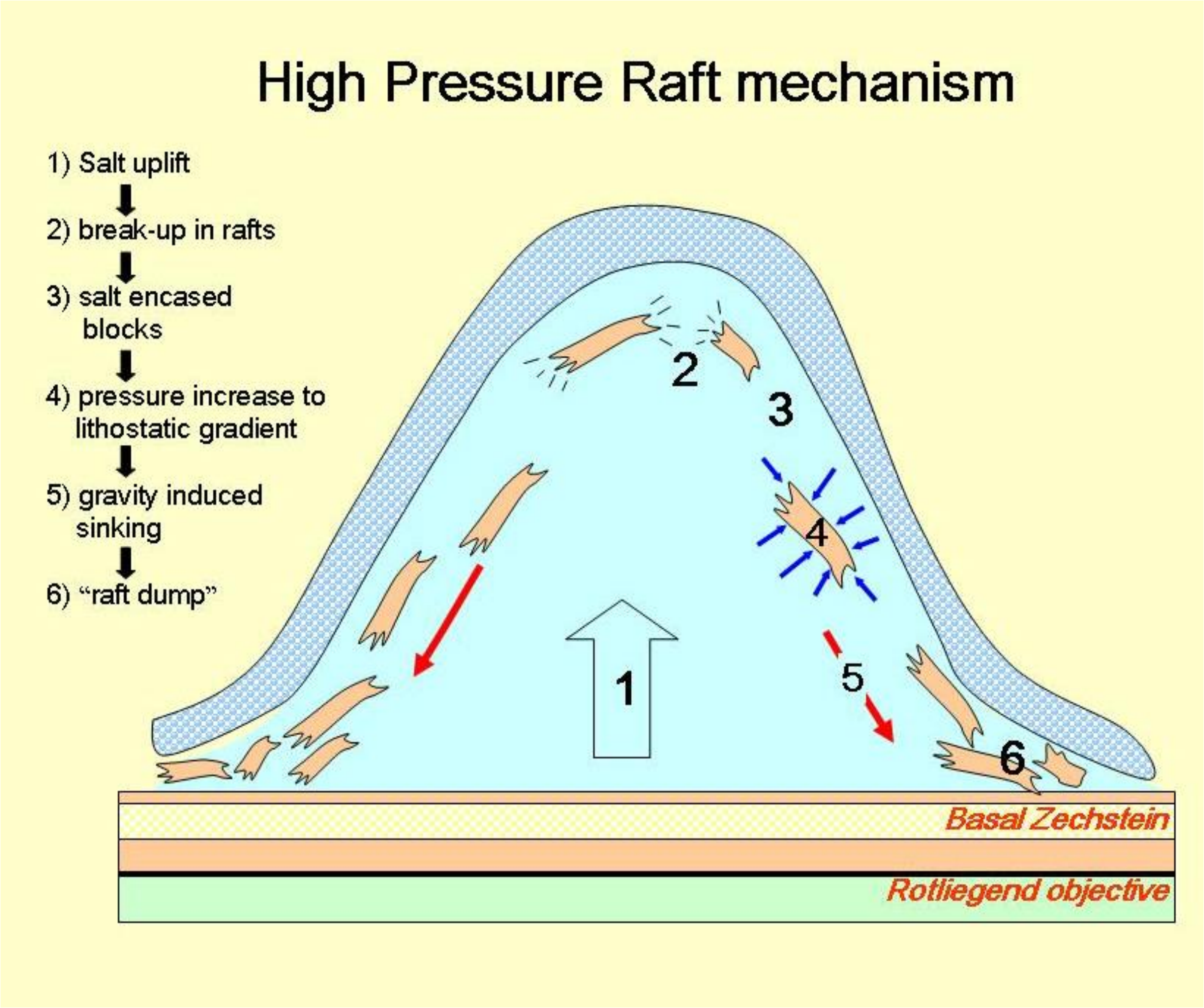
Zechstein stratigraphy: -initially-



Density in gram/ cc

Ref: “*Are salt kicks predictable?* G. Hoetz et al. PESGB geophysical seminar, London 2008

Zechstein stratigraphy: -post deformation-



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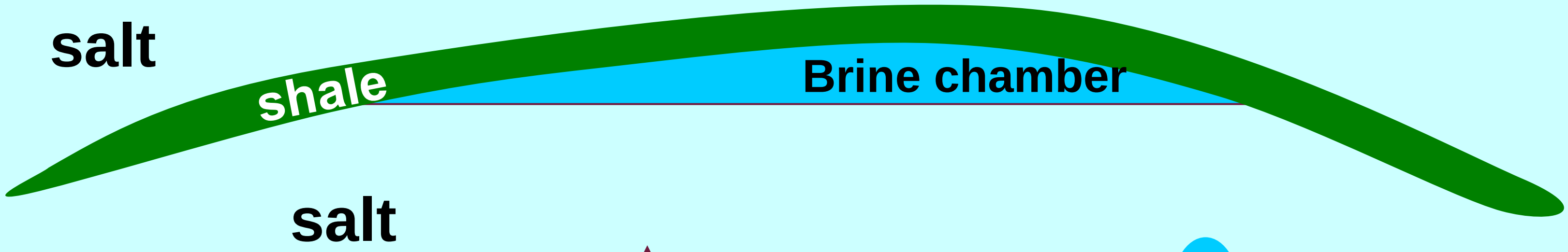
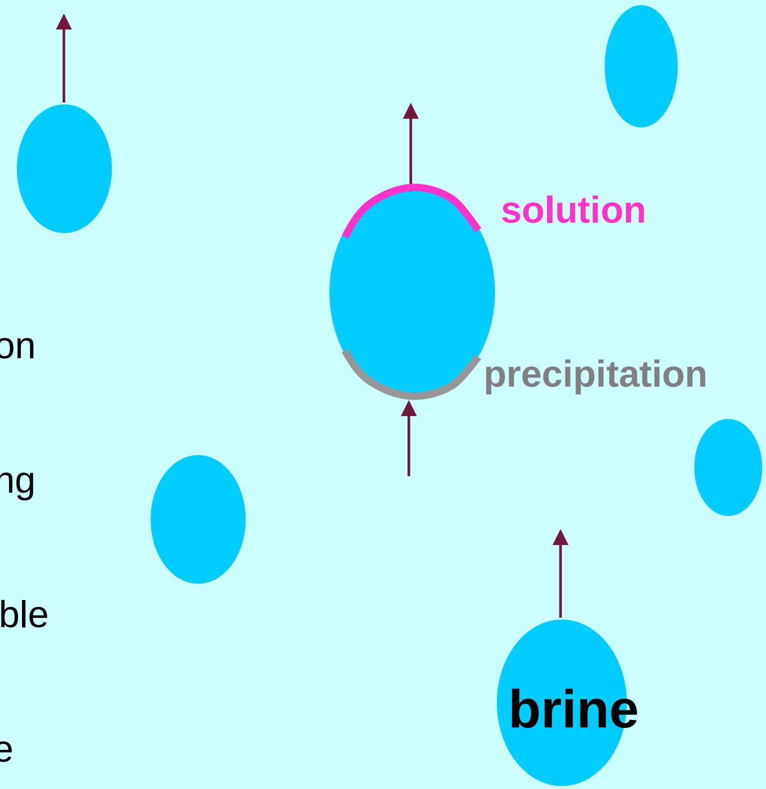
Shale Capped Brine Chamber

-concept-





- Salts contains crystal water
- Increasing burial causes water expulsion
- Brine bubbles migrate upwards due to pressure dissolution and/or micro-fracing (*~semipermeable membrane)*
- Upward migration arrested at non-soluble layer (e.g. shale level)
- Brine accumulates below (mini) closure

Ref: "*Are salt kicks predictable?* G. Hoetz et al. PESGB geophysical seminar, London 2008

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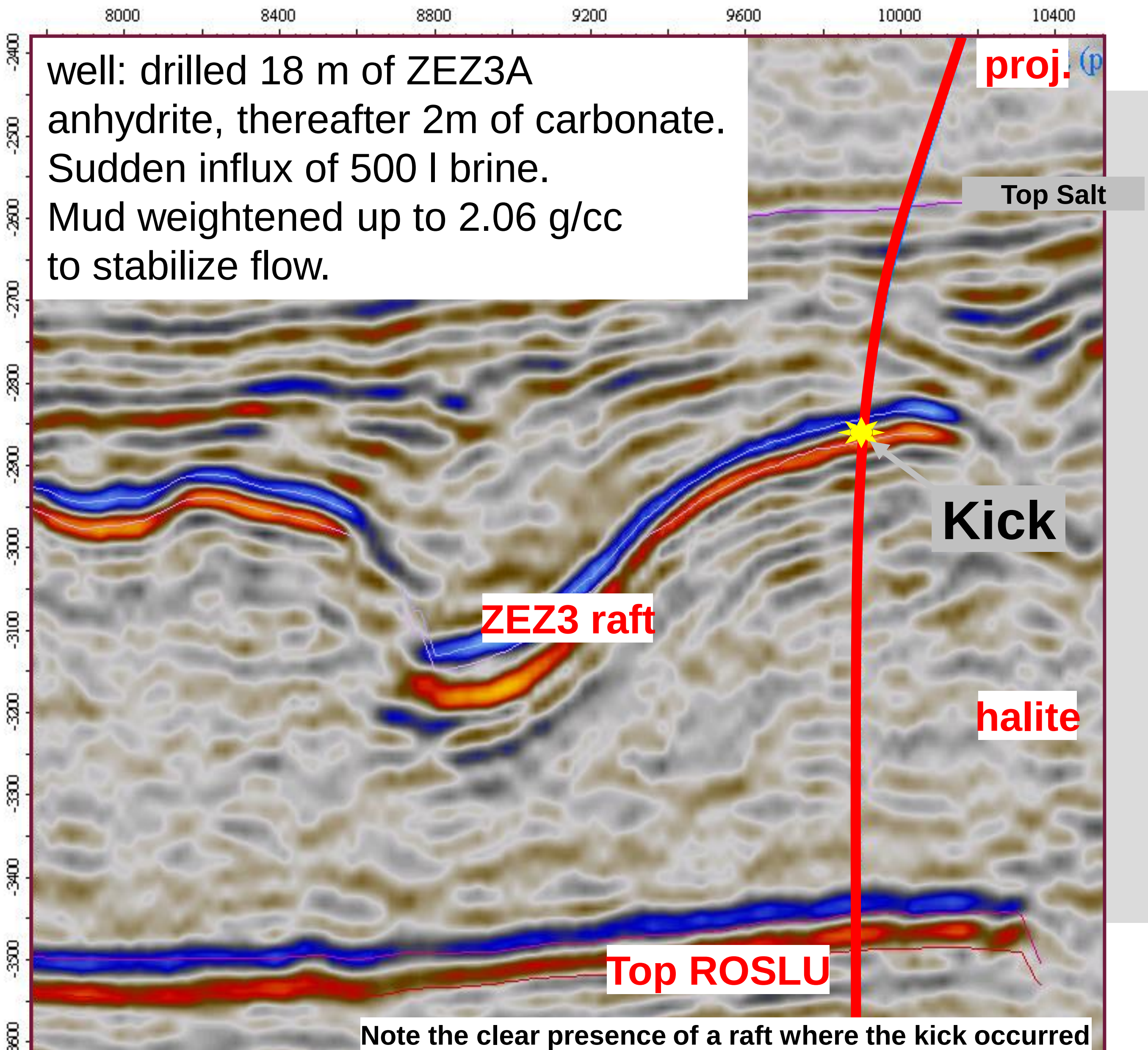
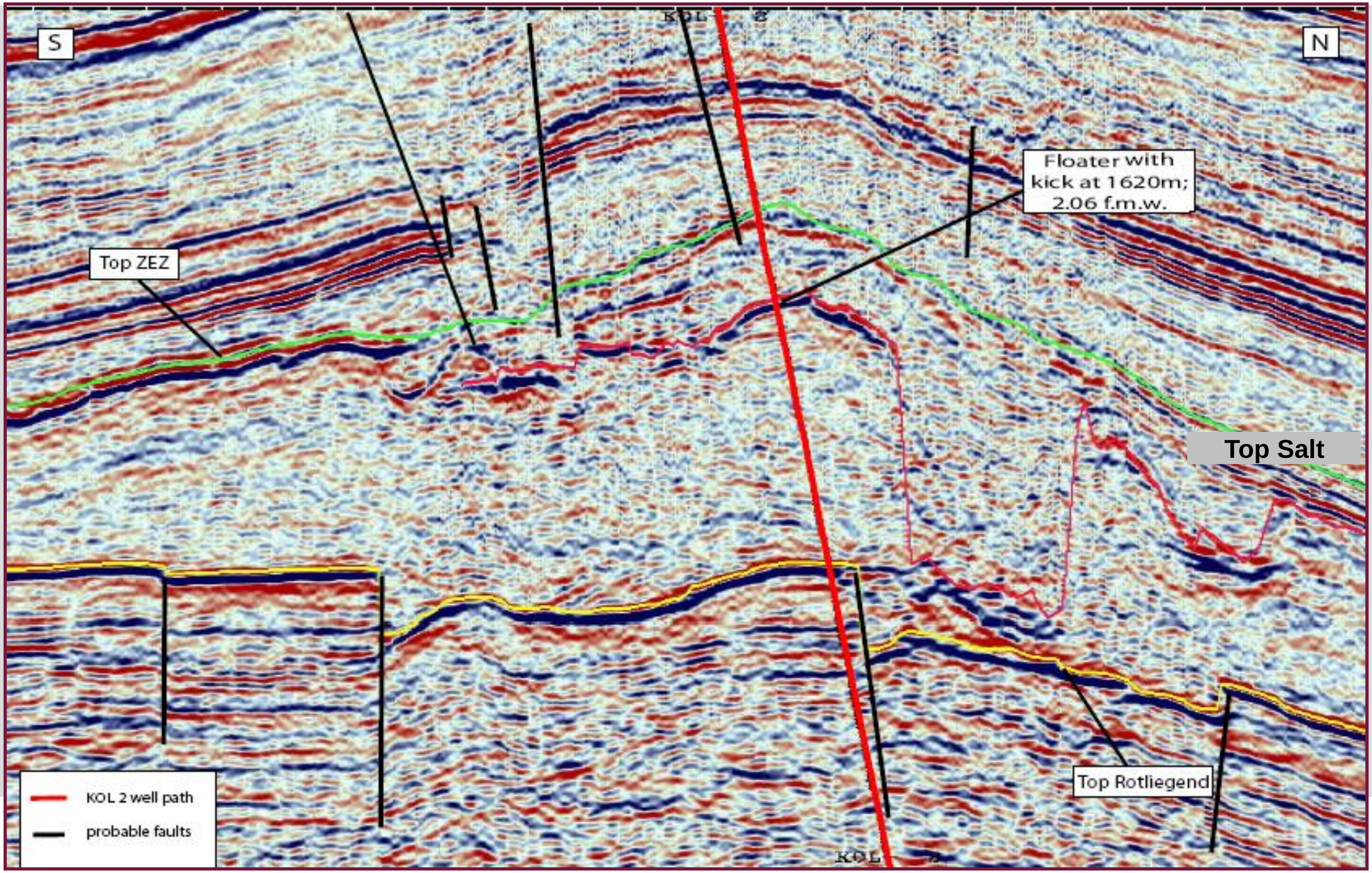
Example #2



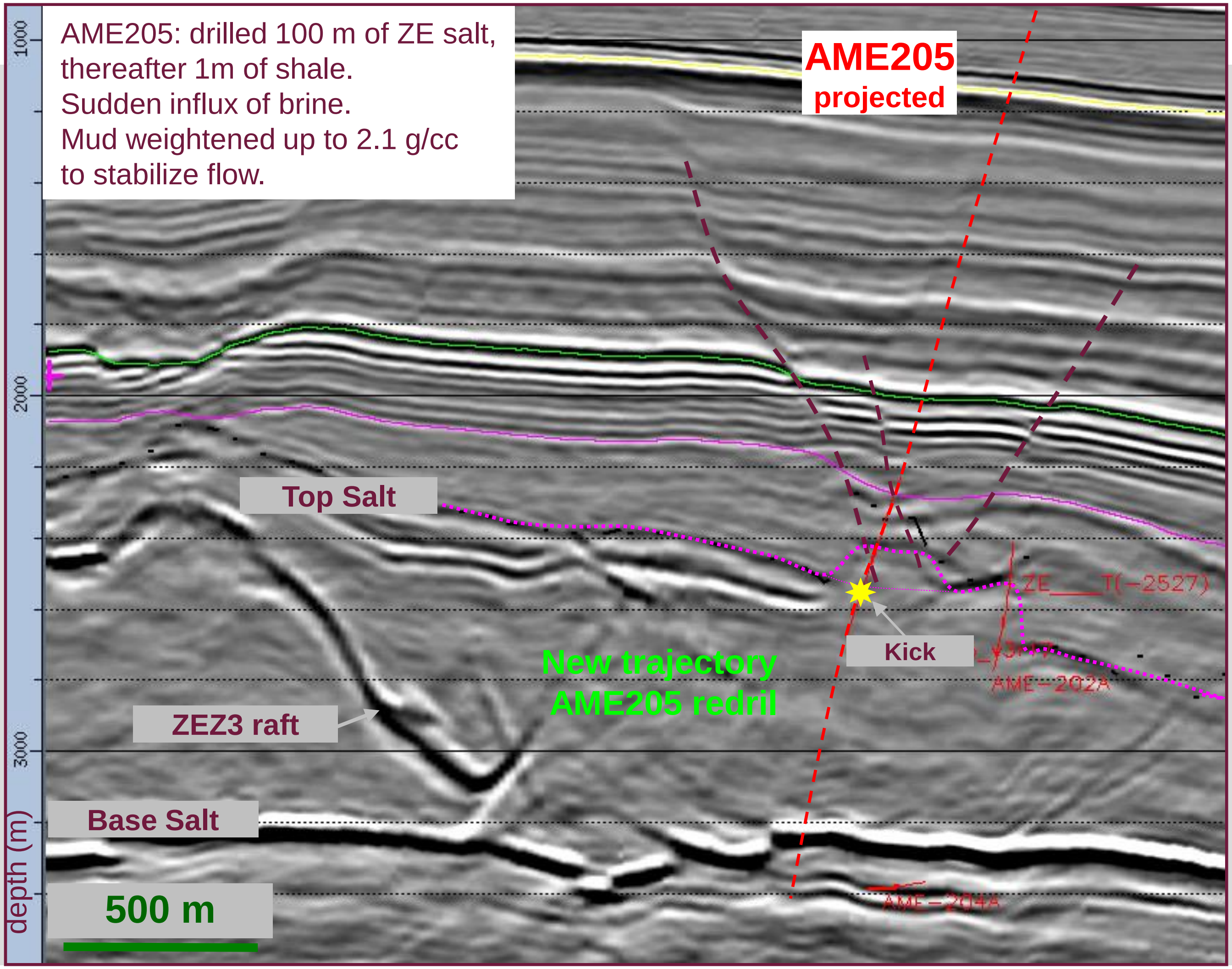
8000
8400
8800
9200
9600
10000
10400
-2400
-2500
-2600
-2700
-2800
-2900
-3000
-3100
-3200
-3300
-3400
-3500
-3600
well: drilled 18 m of ZEZ3A
anhydrite, thereafter 2m of carbonate.
Sudden influx of 500 l brine.
Mud weightened up to 2.06 g/cc
to stabilize flow.
proj.
Top Salt
Kick
ZEZ3 raft
halite
Top ROSLU
Note the clear presence of a raft where the kick occurred

Example #3



S
N
KOL 8
Floater with kick at 1620m; 2.06 f.m.w.
Top ZEZ
Top Salt
Top Rotliegend
KOL 2 well path
probable faults
KOL 2

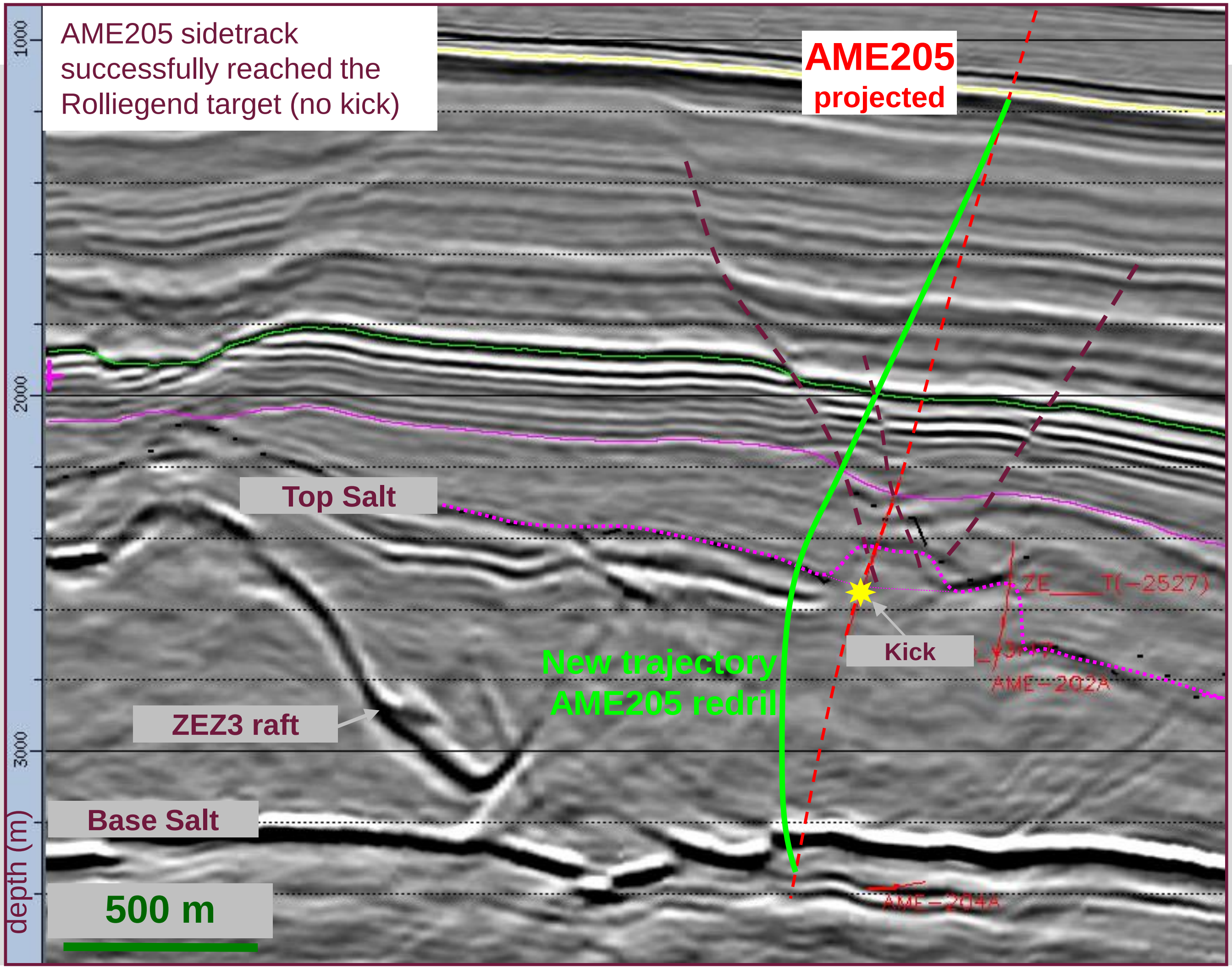
AME-205: brinepocket



Incident led to loss of well & additional costs of 30 mil euro

Ref: "*Are salt kicks predictable?* G. Hoetz et al. PESGB geophysical seminar, London 2008

AME-205 redrill: avoiding the salt protuberance



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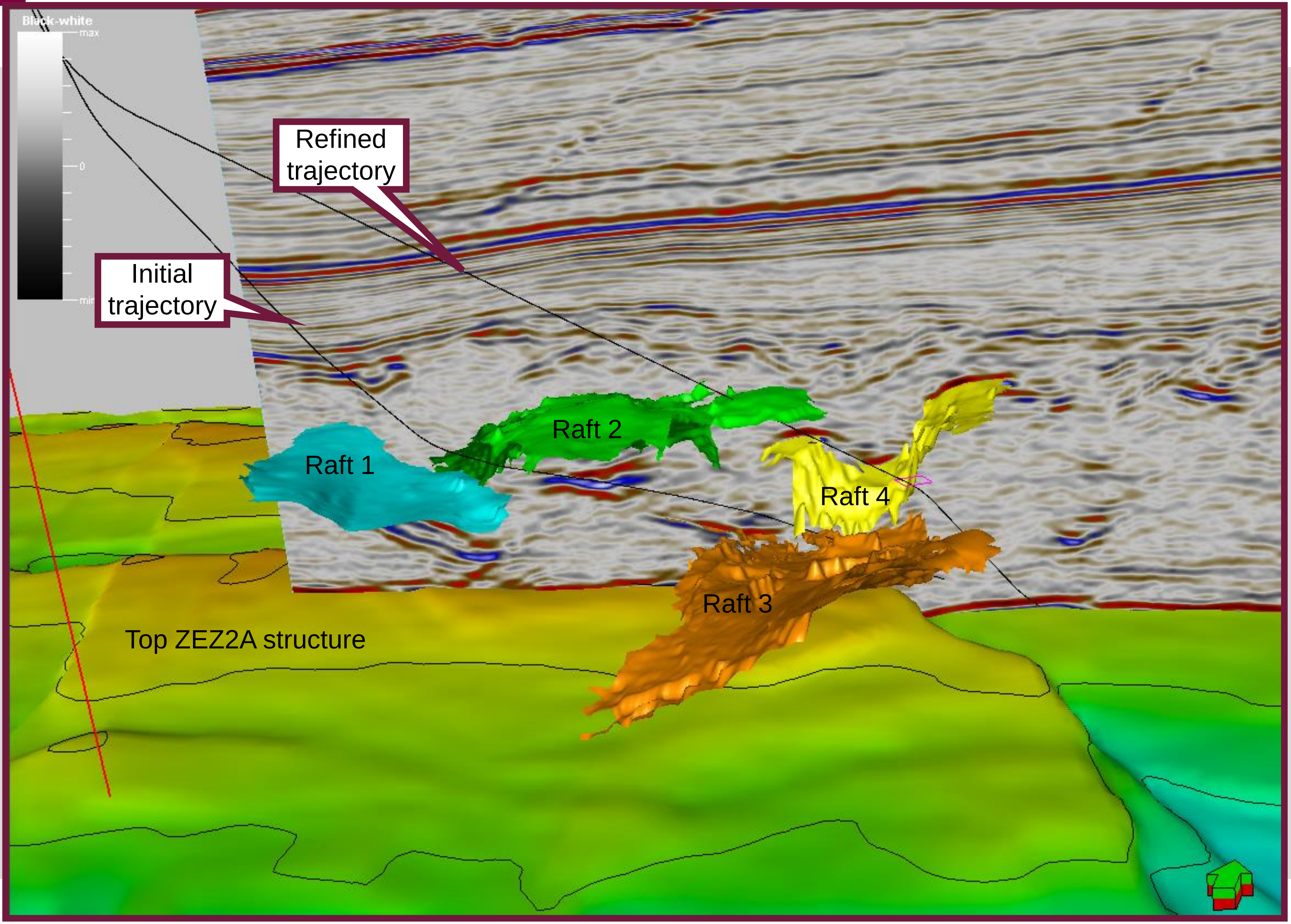
Trajectory planning: dealing with targets & anti-targets



Avoiding Geo-Hazards requires carefull trajectory planning

Overpressures in Zechstein

2 types of High Pressure Brines Occurrences

Raft [1]

1. Always (?) visible on seismic: hard kick event.
2. Visibly fully encased by salt
3. Generally brine (but also HC)
4. Generally originating from ZEZ3A/C: Anhydrite on top of carbonate as seen in cuttings
5. HP influx rate varies: appears related to porosity/ permeability of ZEZ3C
6. Relatively common and well documented

Brine pocket [2]

1. Not (directly?) visible on seismic
2. Always brine: high in Mg
3. No anhydrite / carbonates in cuttings
4. Origin uncertain but appears mainly in upper Zechstein (ZEZ4?)
5. Relatively rare and poorly documented
6. New concept: *shale capped brine chambers explains relation with shales*

[1]) *Also: floaters, stringers*

[2]) *Also: brine chamber*

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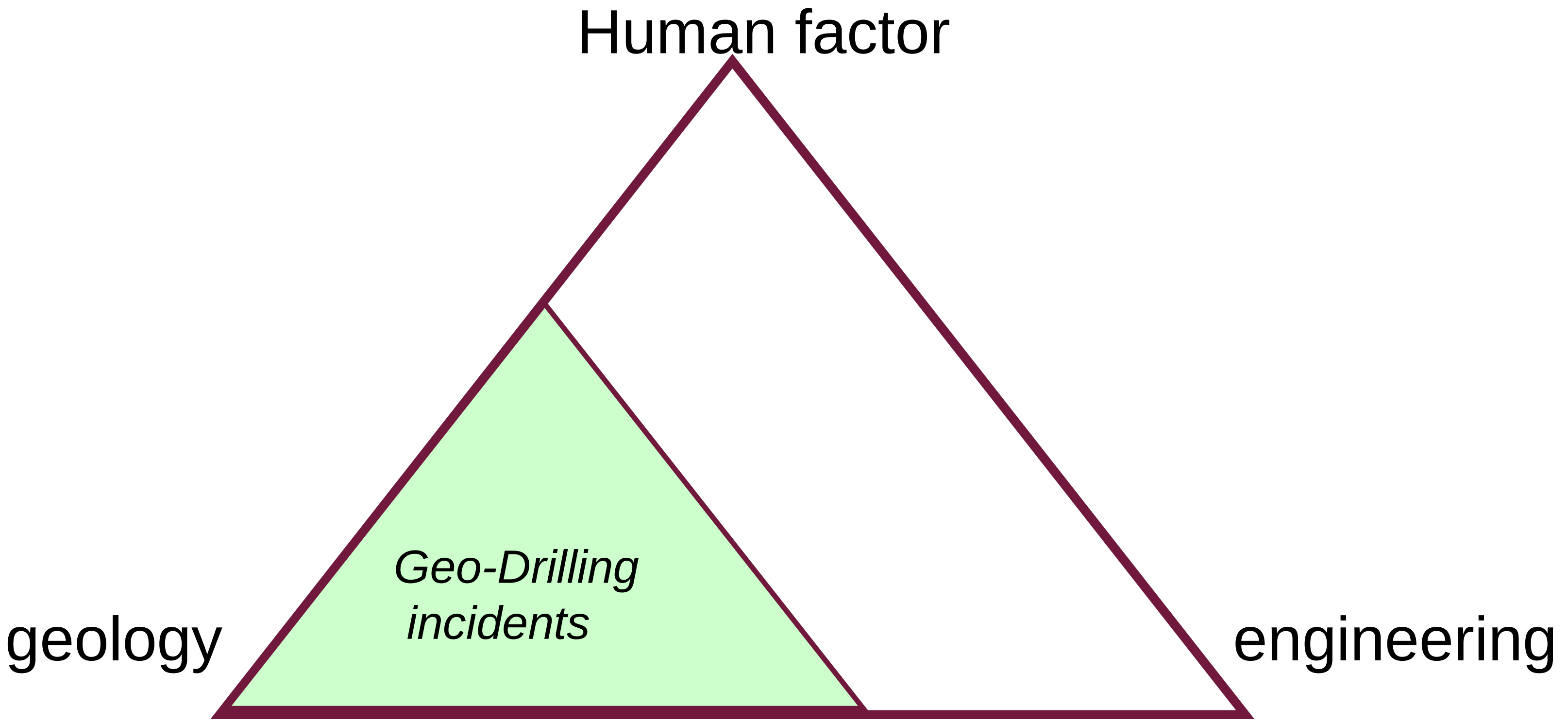
What Drilling Incidents to be captured?

Drilling incidents can have one or more causes: Drilling Incident Triangle



Geo-Drilling incidents have a significant geology component in the cause
Geo-Drilling incidents require geoscientists for understanding
Geo-Drilling incidents can often be avoided by doing geological homework

Ref: Drilling Hazards Inventory: the Key to Safer -and Cheaper- Wells, SPE 166254 G. Hoetz et al.

Drilling Incident and Hazards classification scheme

Drilling Incidents coding based on:

observation and interpretation

Category - Geological Drilling Incident

Type of Drilling Incident Based on observation:

DI_CODE	Type	Description
1	**High Torque/Overpull**	High torque or vertical resistance of the drill/casing string which ca reaming and/or significant hole cleaning.
2	**Collapsed hole**	After RIH again, drilled hole found to be too tight or completely col
3	**Difficult Drilling**	Excessive wear of the drill bit resulting in reduced rate of penetrat
		tion

Category - HAZARDS : Cause of Drilling Incident

Type of Drilling Hazard based on analysis:

HZ_CODE	Type	Description
A	**Abrasive formation**	Formation with abrasive effect on drill bit. The abrasive effect is caused by an high content of hard m chert.
B	**Boulders**	Large detached rocks in borehole. Typically originating from conglomerate. Can lead to trapped drills
S	**Squeezing formation**	Borehole formation deforming under the influence of drilling activity (e.g. ductile behaviour). Movem (undergauge hole), leading to stuck pipe, excessive bit wear/reaming/clayballing/gumbo etc.
W	**Unconsolidated/weak formation**	Unconsolidated formation, collapsing into the hole

Ref: Drilling Hazards Inventory: the Key to Safer -and Cheaper- Wells, SPE 166254 G. Hoetz et al.

Are salt kicks predictable?
To some extent

1. Scale of phenomena/ rock props do not allow conventional inversion/ velocity analysis
2. Rafts can generally be identified on (3D) seismic
3. Raft geometry gives indications on pressure (*encased body*)
4. Raft deformation might give indications on Productivity Index (*fracture permeability*)
5. Brine chambers are subseismic (?)
6. Brine chamber risk increased in heterogeneous & distorted salt (*shale drapes*).
7. No lithostatic pressures with thin salt cover (*e.g. < 80 meter*)

Conclusions

1. **Salt rheology differs from ordinary rocks**

2. **Salt constitutes exceptional challenges to drillers**

3. **Understanding salt behavior helps in well design**

4. **Seismic helps in defining well targets and in planning wells safely**

5. **Offset well knowledge is key: methodology proven by TNO pilot**