Charge and Leakage Analysis Integrating Different Scales: From Fluid Inclusions to Seismic Attributes, Loppa High, Barents Sea, Norway*

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Abstract

The Loppa High (Norwegian Barents Sea) is a large (±150km long, ±100km wide) tilted fault block containing Paleozoic carbonates, covered by Triassic shale-dominated deposits. The Paleozoic contains reservoirs in Carboniferous to Permian carbonates of the Gipsdalen Group. A well, 7220/6-1, was drilled close to the apex of this paleohigh, encountering oil shows in Gipsdalen carbonates. Similarly, three wells drilled in the southern portion of the paleohigh only encountered shows, no hydrocarbon accumulations.

The negative result of well 7220/6-1 might be ascribed to one or several of the following factors: (1) insufficient charge, (2) no reservoir, (3) no valid trap, or (4) leakage. In order to ascertain which of these explanations is correct, a study was carried out in which the hydrocarbon system was analyzed at a variety of scales, ranging from fluid inclusions, through cores and wireline logs, to seismic scale.

Seismic interpretation, using recently developed attributes, focused on faults (reservoir compartmentalization, fault reactivation, leakage, etc.) and facies (carbonate build-ups versus muddy “lagoons”, karst). Well 7220/6-1 is not located in a zone of buildups, and the karst processes apparent in the cores and image logs point to low-porosity, senile karst; however, core and log analysis indicate a moderate porosity with, in places, fair permeabilities. So, factor (2) was discarded.
Seismic interpretation indicated the presence of leakage, aided by faults. Shallow bodies of high amplitude may represent locations of the migrated hydrocarbons. The presence of "paleo-pockmarks" on the top Triassic unconformity indicates gas leakage before the Quaternary. Log analysis suggests that the oil observed in the well is dead oil; this, together with the presence of a possible paleo-oil-water contact, points to initial trapping of oil and subsequent leakage due to fault reactivation: factor (4). However, factor (3) should not be ruled out altogether.

Geochemical and basin analysis indicates that the oil in the well has a Paleozoic source, probably with a Triassic admixture, and that most oil migration occurred before the Tertiary uplift. This is confirmed by PVT analysis of fluid inclusions. However, migration pathways from these sources appear to be somewhat difficult, and factor (1) may have contributed to the absence of an accumulation in well 7220/6-1.

It is concluded that leakage probably is the main cause of the negative result of well 7220/6-1.

References

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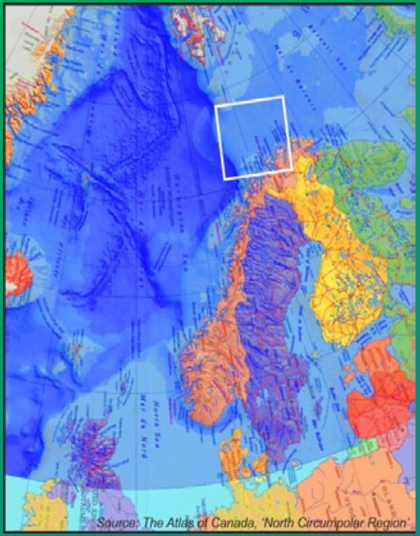
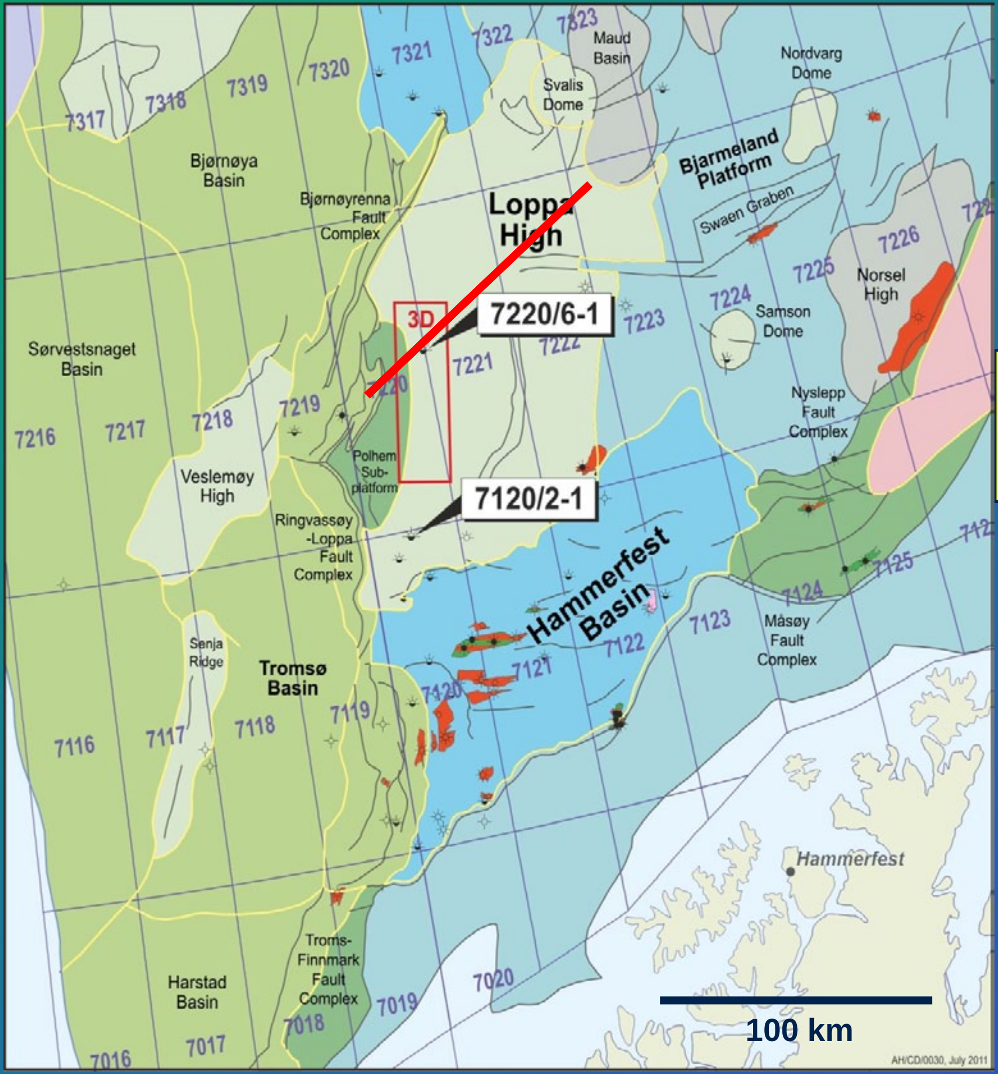
- **Introduction**
- Reservoir: sedimentology & petrophysics
- Trapping
- Leakage
- Charge
- Conclusions

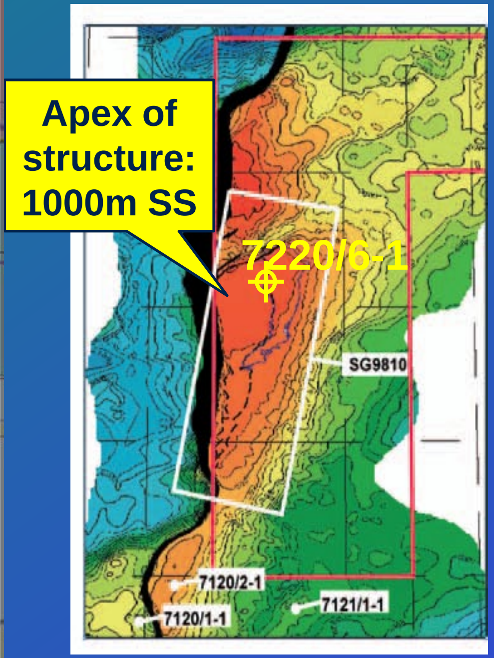
The Loppa High is a large, pretty structure in the Barents Sea …

… but a well drilled near the apex only had some shows. Does this condemn the rest of the structure?

Barents Sea & Loppa High
Location map

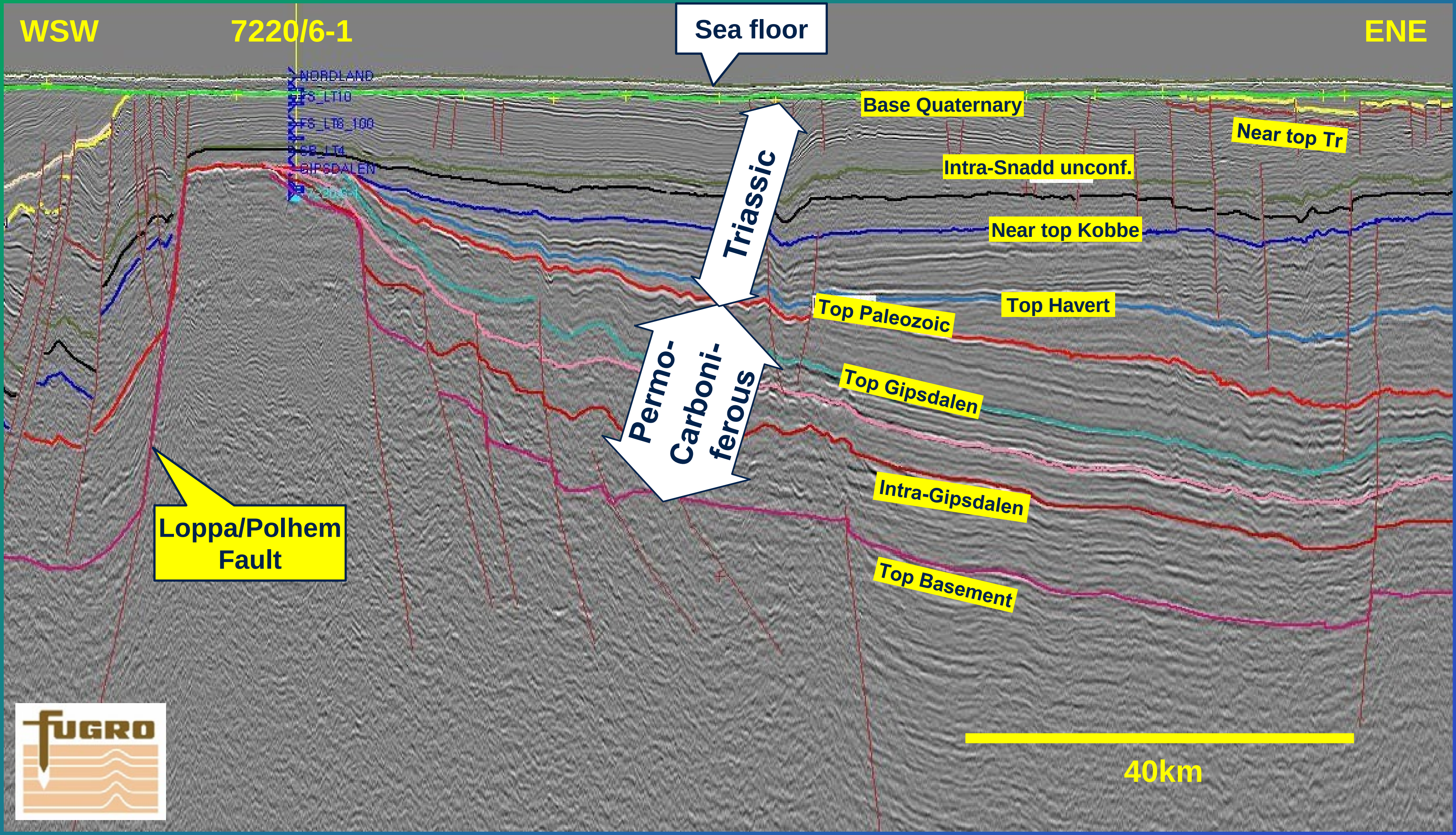




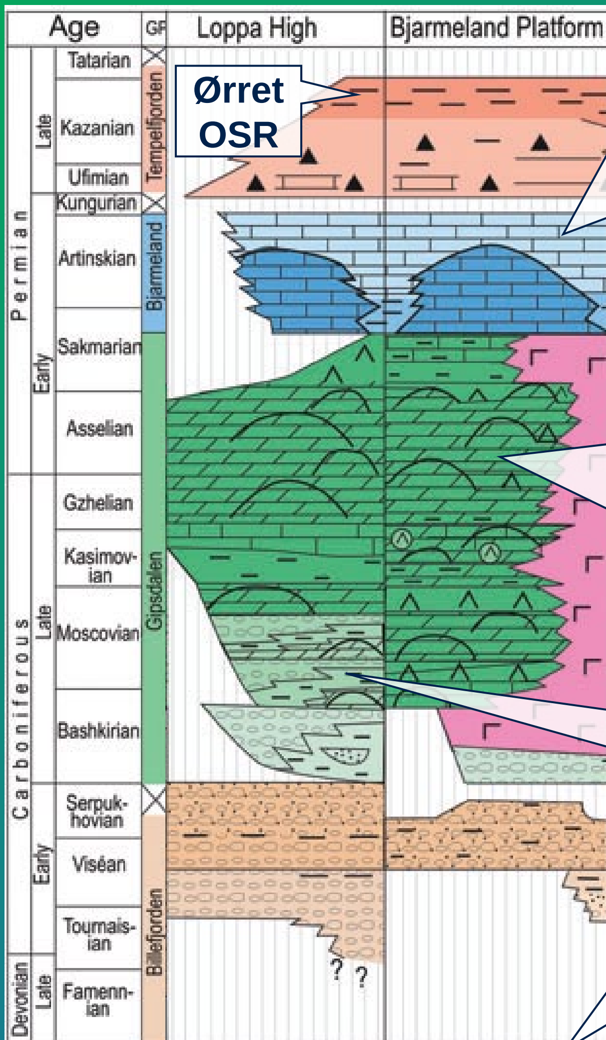


Carrillat *et al*., 2005

Loppa High
Seismic line through well 7220/6-1



Barents Sea
Upper Paleozoic stratigraphy



Ørret OSR

Bjarmeland/ Tempelfjorden groups: cold-water carbonates. Considered less prospective.

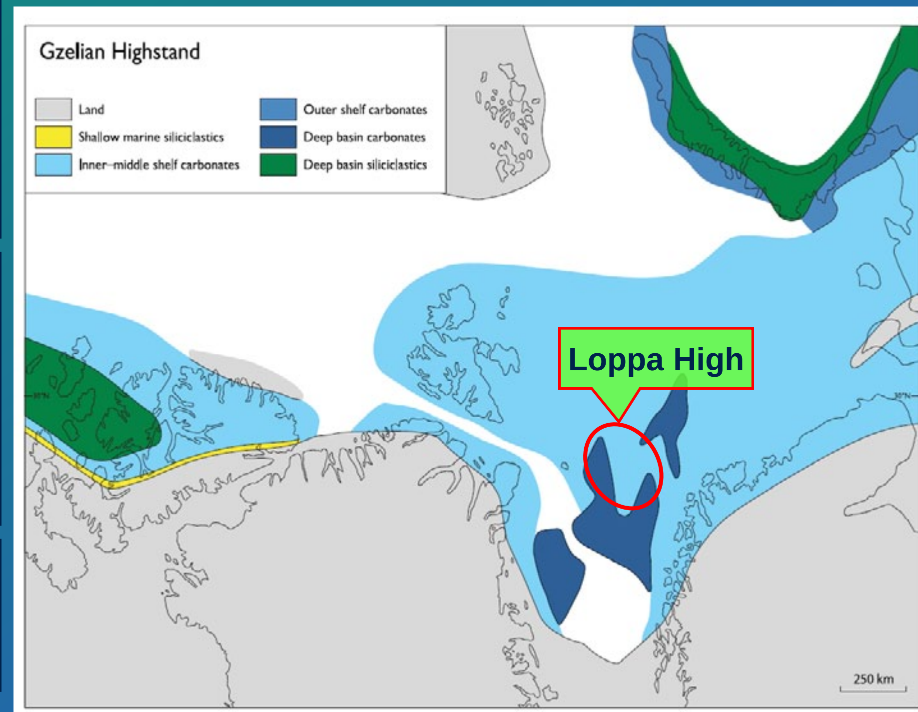
Ørn Formation, Gipsdalen Group: warm-water carbonates. Considered most prospective.

Falk Formation, Gipsdalen Group: basal clastics

Basement: fractured quartzite

Larssen et al., 2005

Gzelian: Ørn Fm. carbonates



Stemmerik & Worsley, 2005

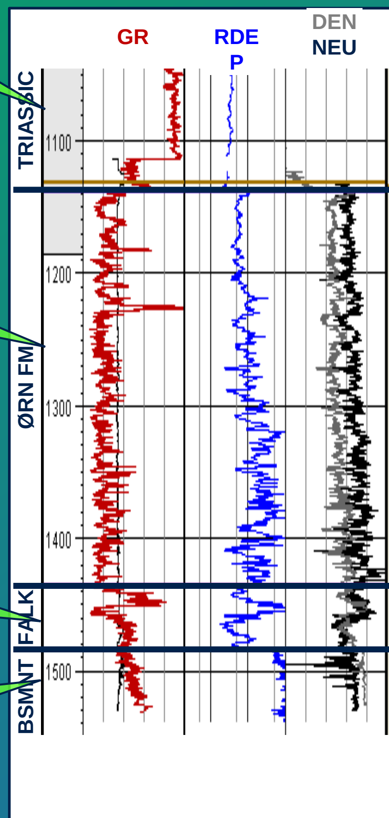
Well 7220/6-1
Logs & shows

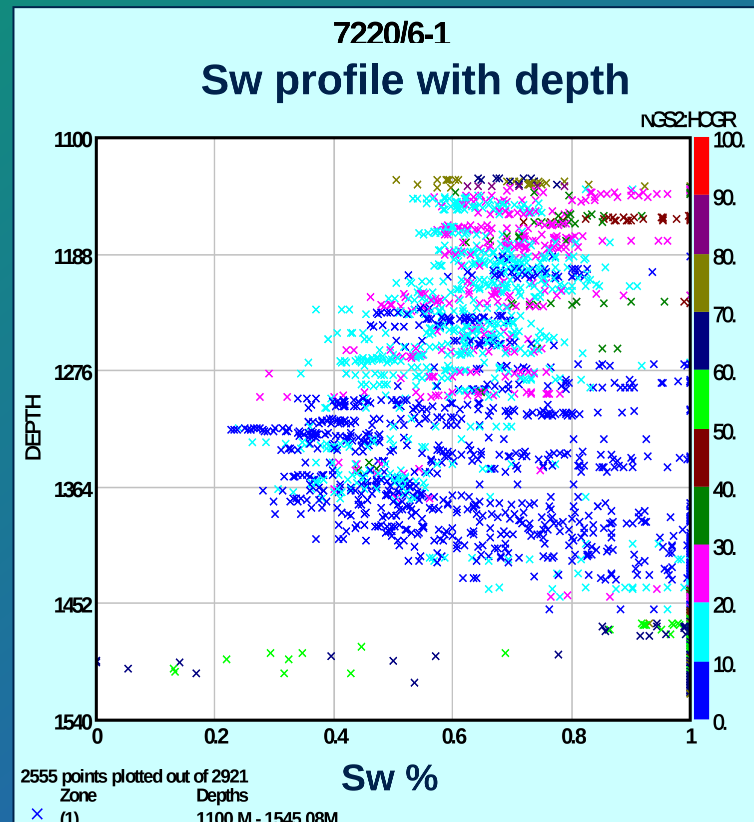
Triassic: Shale-dominated

Gipsdalen carbonates

Gipsdalen basal clastics

Quartzitic basement





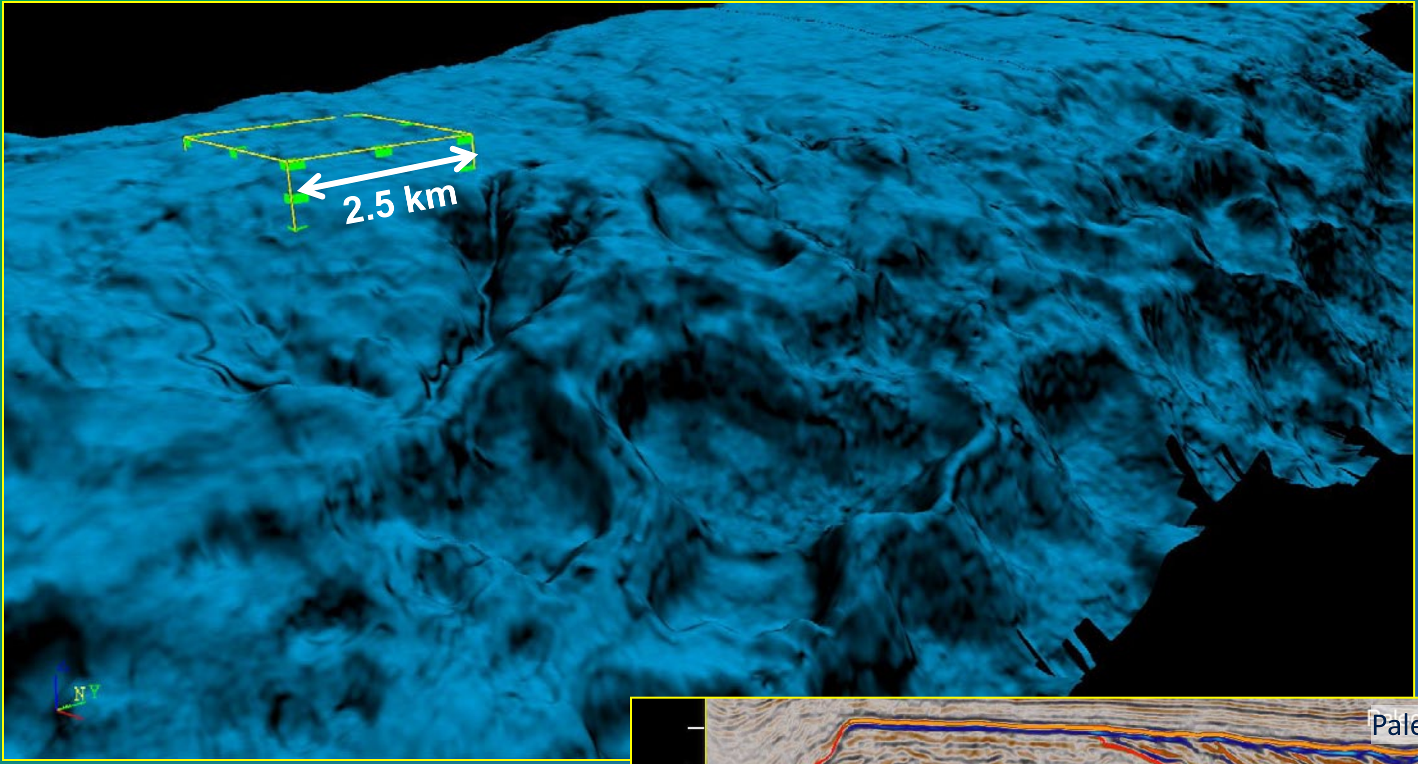
Residual hydrocarbons and good oil shows were obtained in carbonates of the Gipsdalen Group, Ørn Formation from 1138 m and down to 1430 m (NPD FactPages).
The well was not tested.

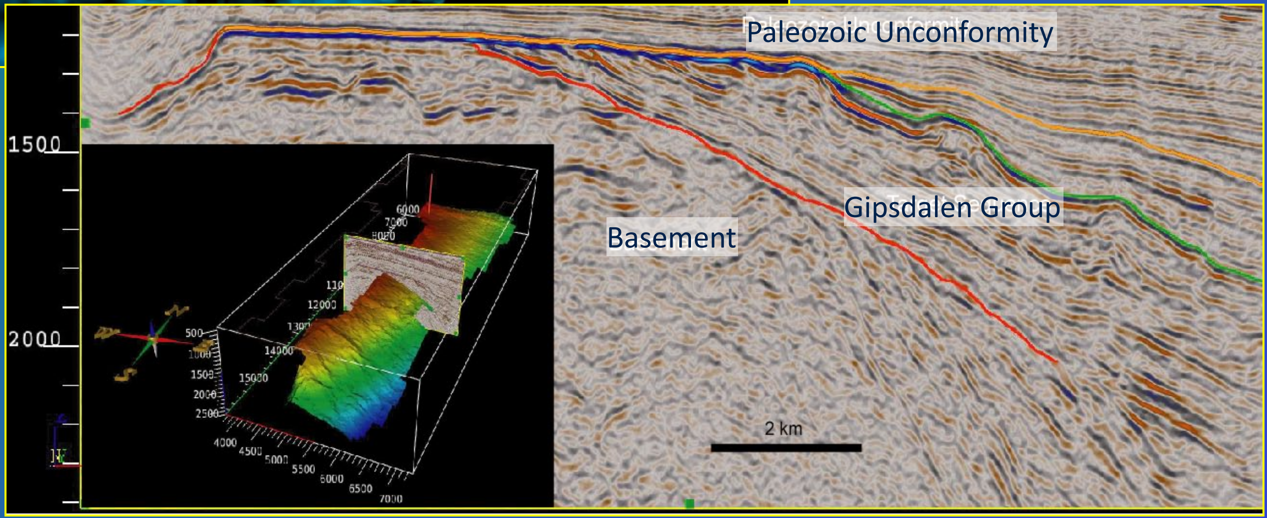
Contents

Well 7220/6-1 did not fail because of poor reservoir quality

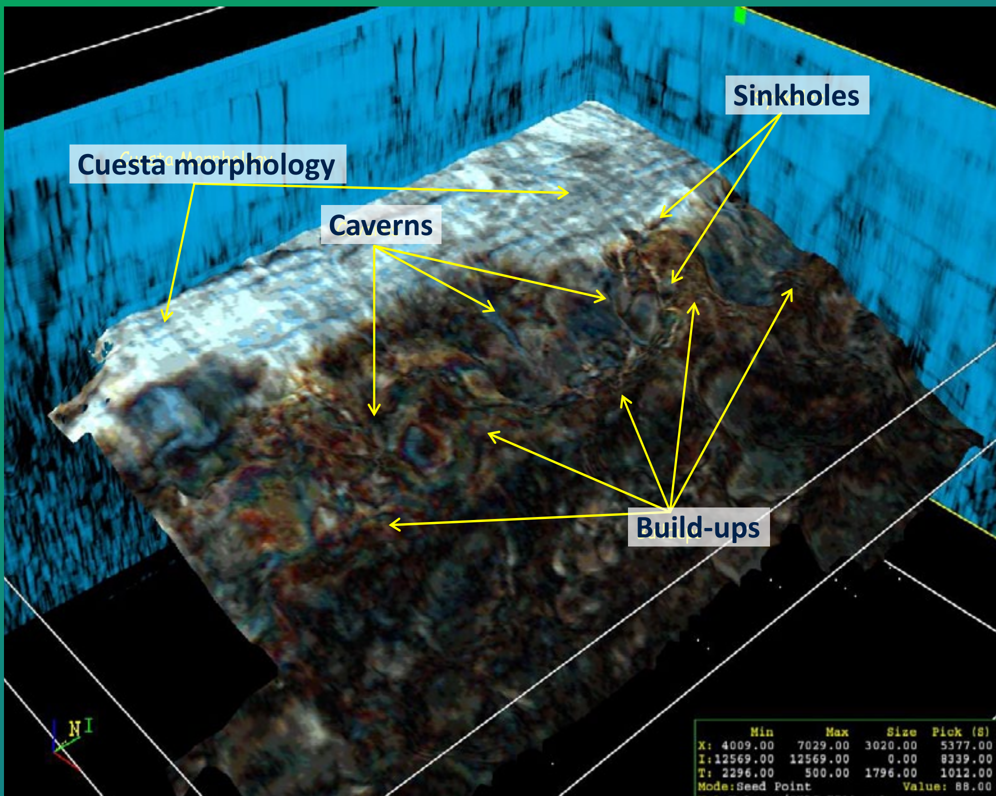
Good reservoir quality may be expected in spite of moderate reservoir quality at 7220/6-1

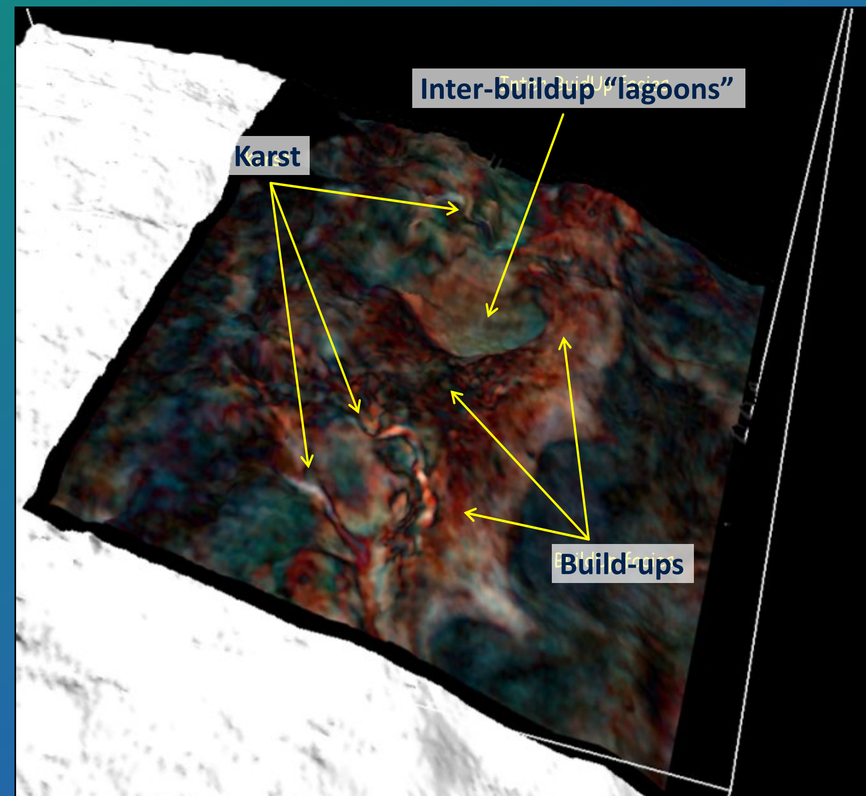
Carbonate buildups at top Gipsdalen





Seismic shows buildups and karst features





Examples of the use of spectral decomposition to obtain a better image of karst features and buildups.

Well 7220/6-1
Sedimentology indicates advanced karst

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Conglo-breccia with vuggy porosity and late blocky calcite cement.

Dolomitic conglo-breccia with mechanical and chemical compaction.

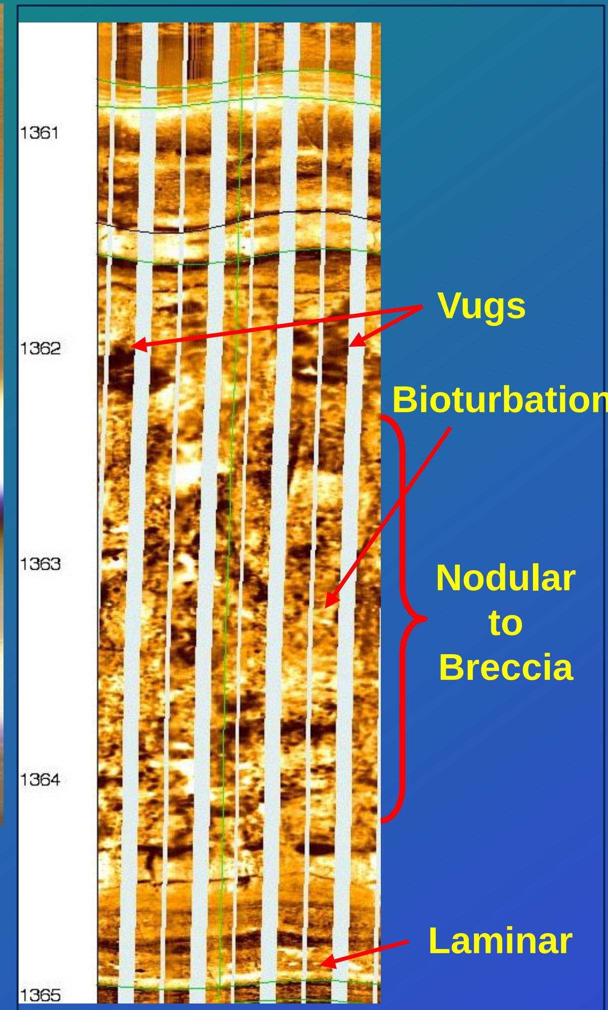
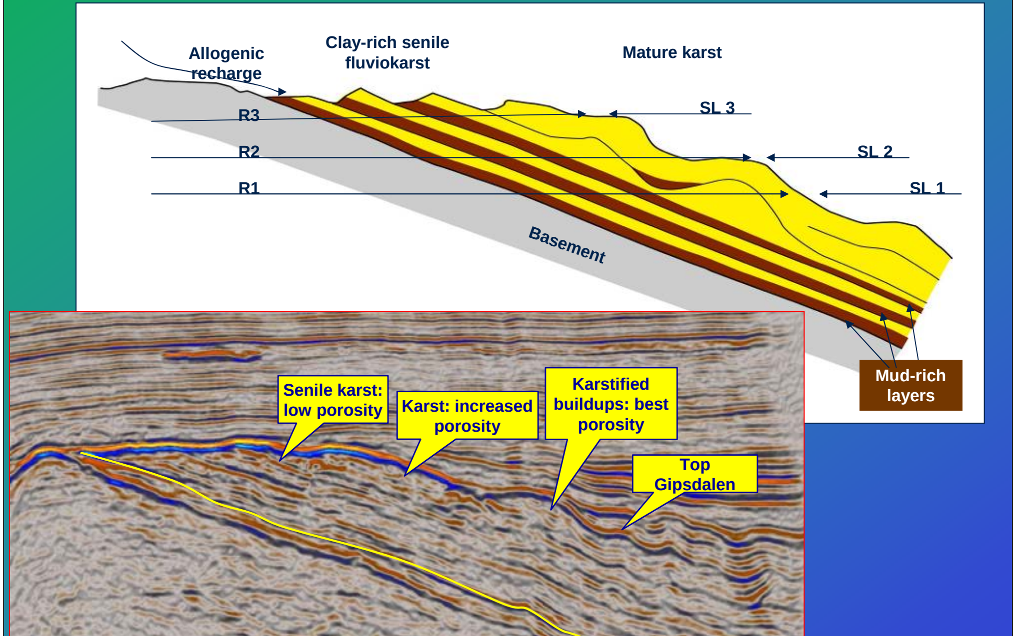


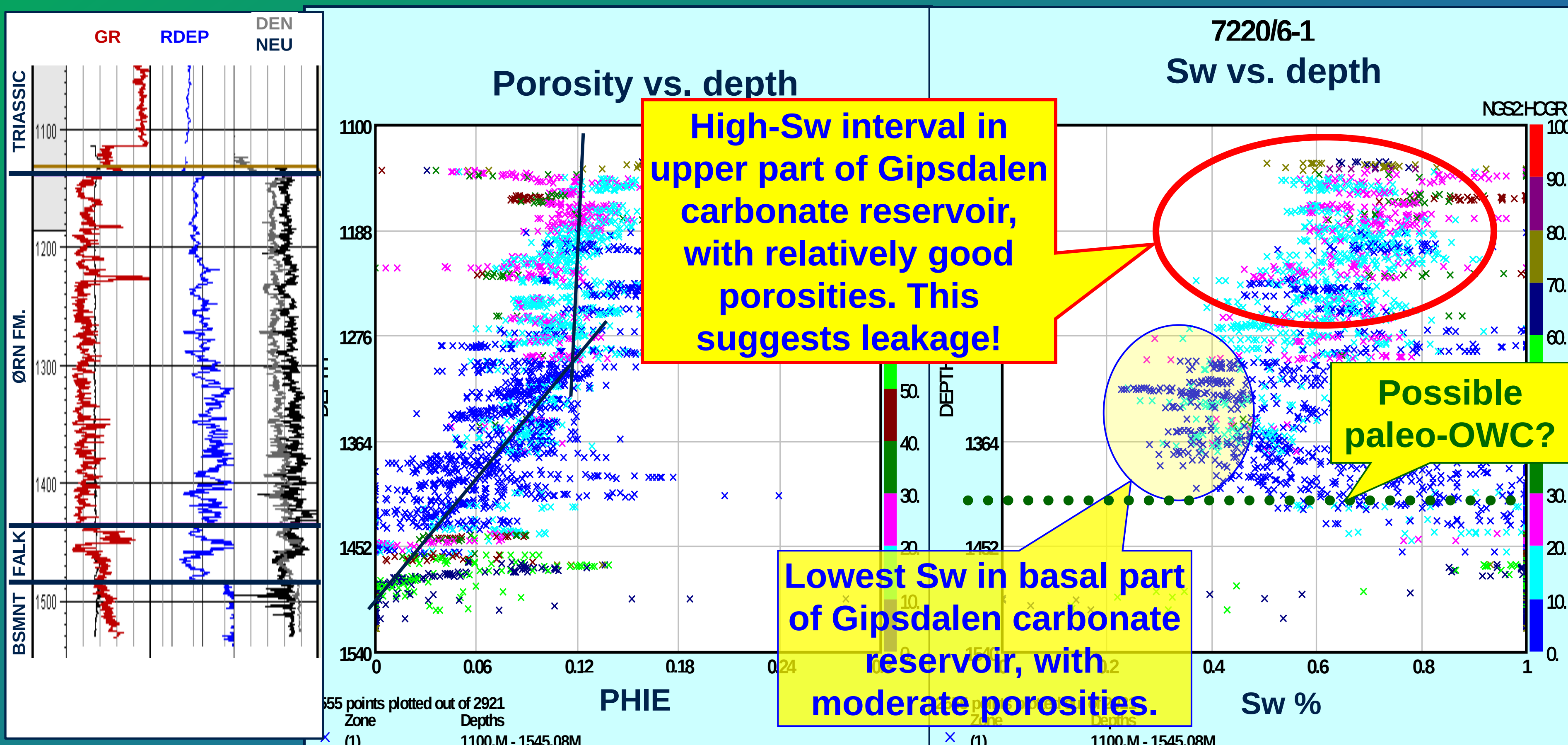
Image log (dynamic normalization)

Loppa High
Model for karst development

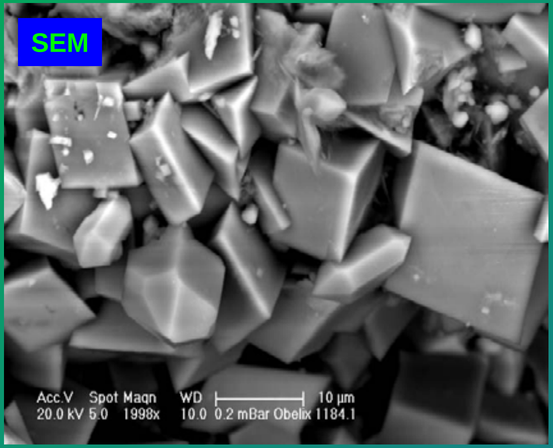


Presenter's notes: General scheme of meteoric karst development in the Loppa High. Evolution levels (SL 1 to 3) essentially determine the recharge area (R1 to 3) and the corresponding hydraulic head. The onlap of the Tempelfjorden section is correlated with a rapid evolution into karst senility (porosity obliteration by sedimentation, collapse, and cementation). The highest parts of the Loppa High will correspond to the most senile karst profile, including abundant intercalations of clay-rich units that contribute to poor rates of karst porosity generation and increased karst sedimentation.

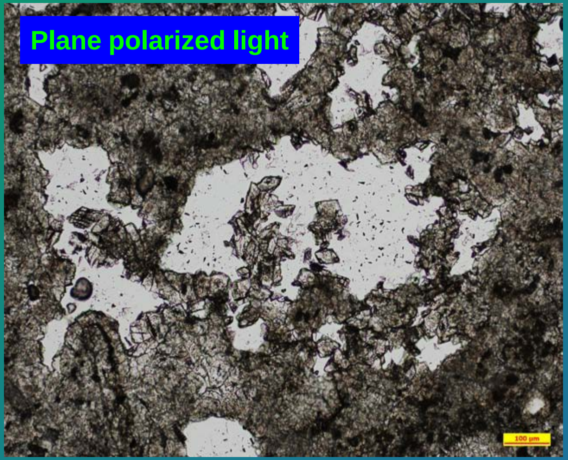
7220/6-1 Petrophysics
Porosity & water saturation versus depth



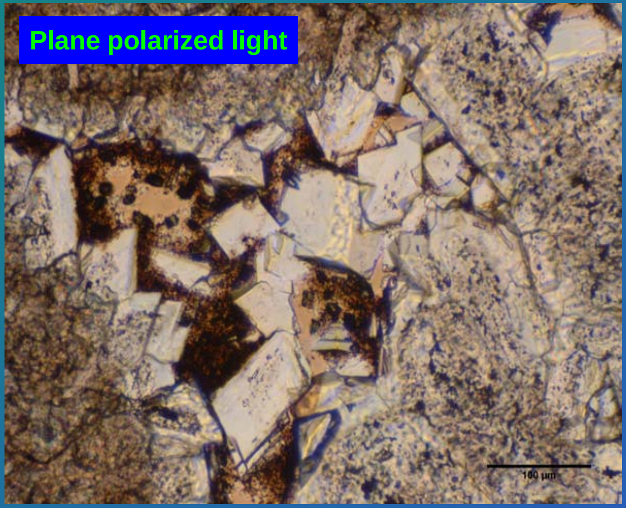
Petrography
Porosity & bitumen

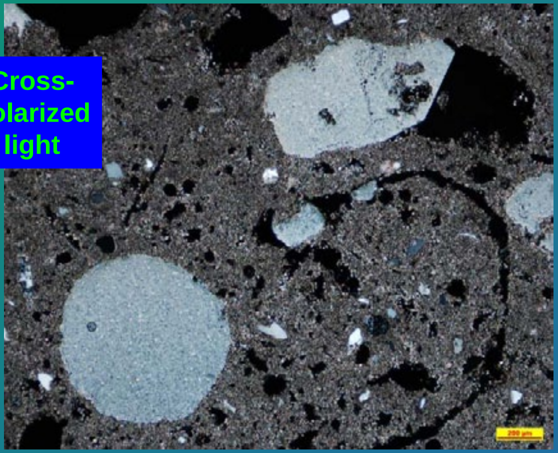


Dolomite crystals and intercrystalline microporosity.

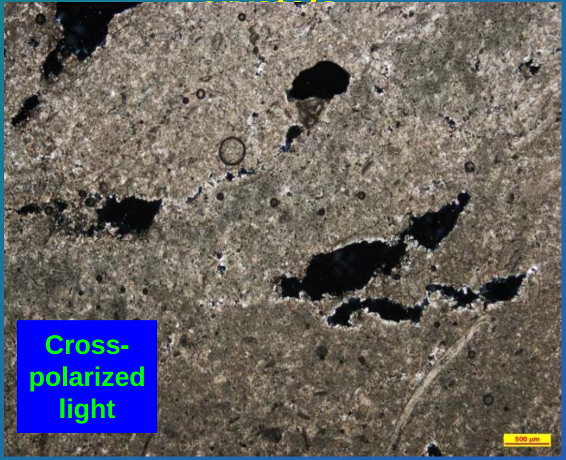


Vuggy porosity enhanced by corrosion of dolomite crystals

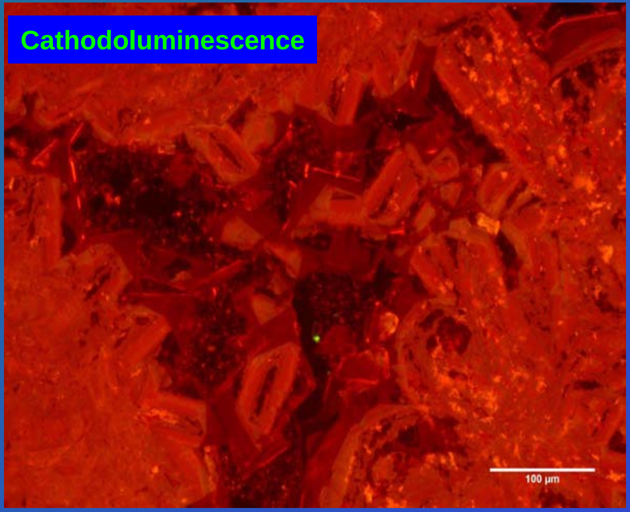




Moldic porosity completely/partially filled by calcite cement.



Dolomicrite with corroded fossil remains giving rise to vuggy porosity.

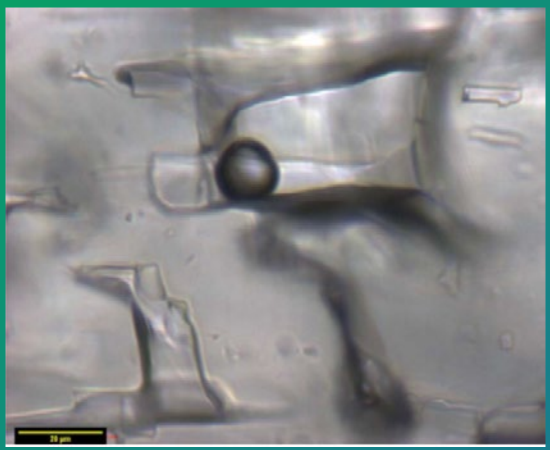


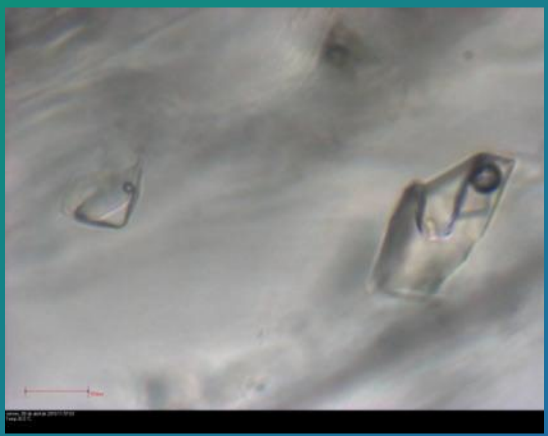
Bitumen impregnation after intergranular dolomite cement precipitation.

Fluid inclusions

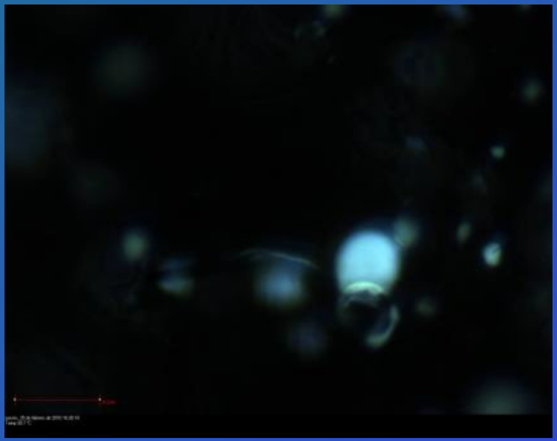
Aqueous inclusions: Water (saline brine) + vapor bubble	Hydrocarbon inclusions: Liquid HCs + methane bubble	Mixed inclusions: Water + HC bubble + vapor bubble

Plane polarized light



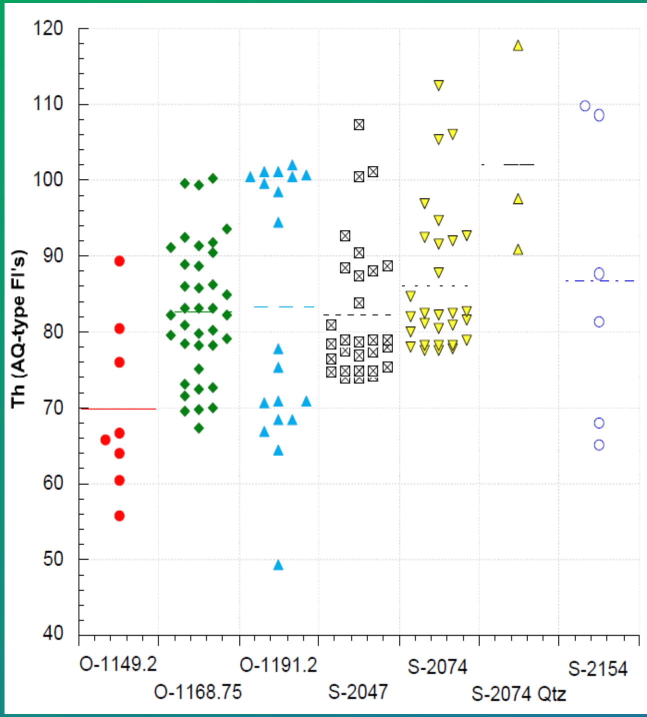


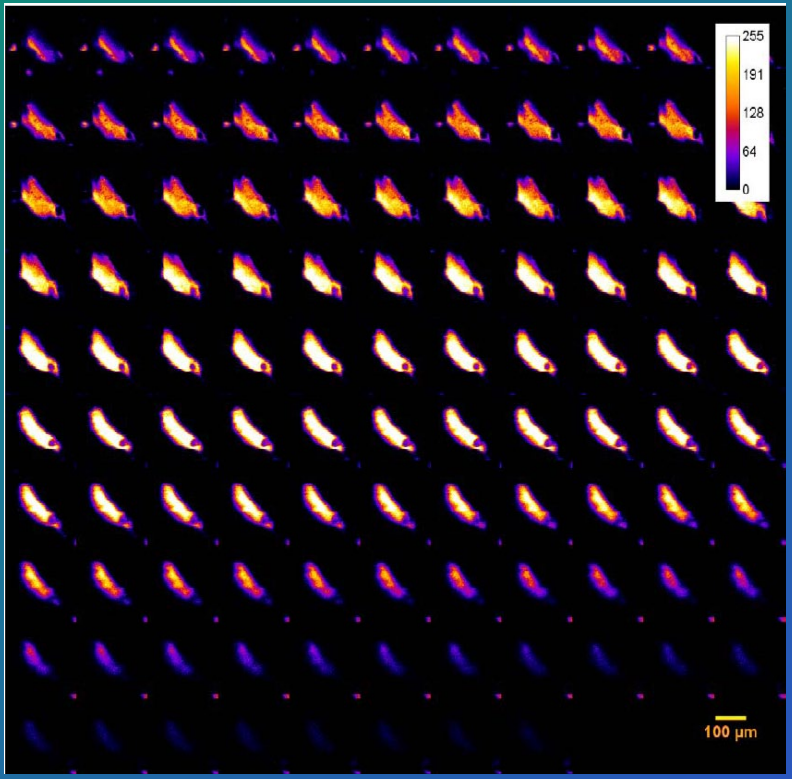
UV light



Well 7220/6-1, 1168.75m	Well 7120/2-1, 2154m	Well 7220/6-1, 1168.75m

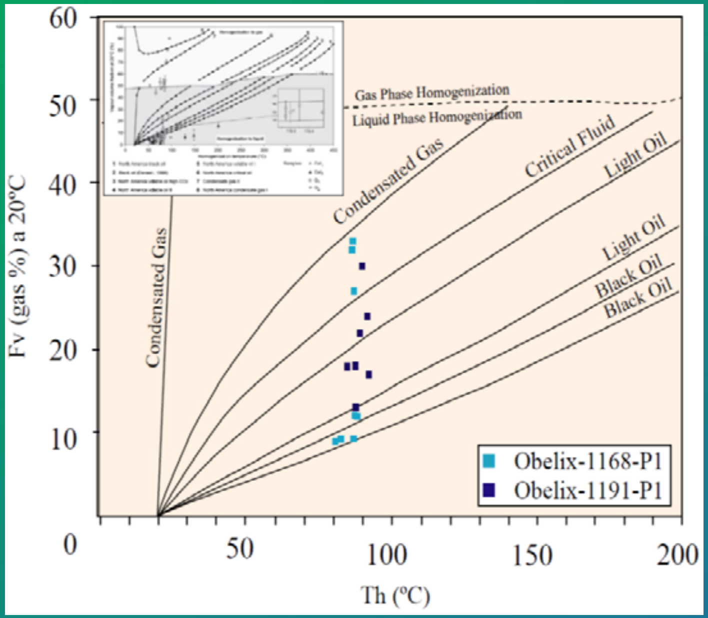
Fluid inclusions
Gas proportion & homogenization temp.



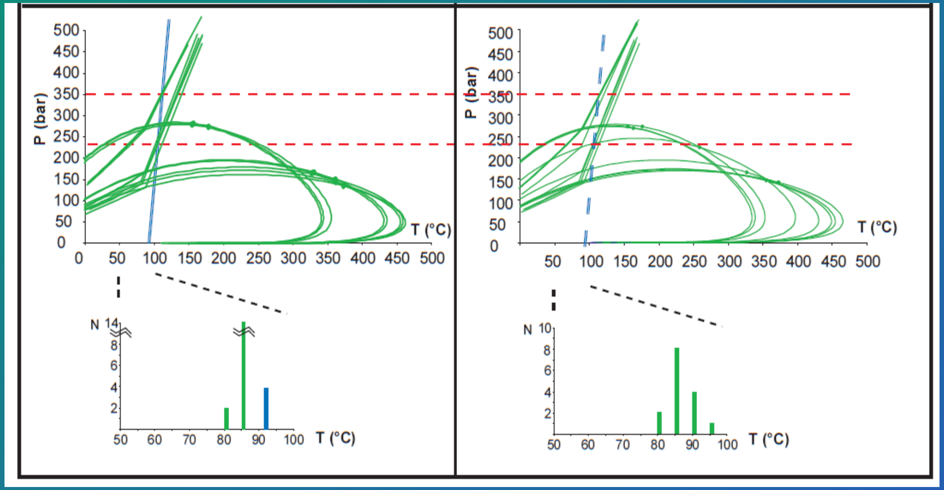


- ✓ **Fluid-inclusion homogenization temperature (Th) gives an indication of the temperature at which the inclusion formed.**
- ✓ **For hydrocarbon-bearing fluid inclusions, Th is in the 58-93 °C range, with a peak at 80 °C.**
- ✓ **Methane proportions (Fv) in hydrocarbon-bearing fluid inclusions can be determined using single-inclusion tomography.**
- ✓ **Fv values obtained range from 7 to 32%.**
- ✓ **Lowest Fv values reflect leakage of gas out of the fluid inclusion, possibly due to decompression following uplift.**

Fluid inclusions
Oil typing & PVT



- ✓ The type of the oil trapped in fluid inclusions can be determined by crossplotting Th and Fv.
- ✓ Oil type, in crossplot, ranges from black oil to light oil/condensate.
- ✓ Since the lowest Fv values are not representative of conditions during fluid inclusion formation, the oil at that time was likely light.



Isopleths and isochores

PVT analysis of fluid inclusions can be carried out using PIT (Petroleum Inclusions Thermodynamics) modeling:

Sample	Trapping temp. (°C)	Trapping pressure (bar)
1168.75m	90-105	230-300
1191.2m	80-100	230-350

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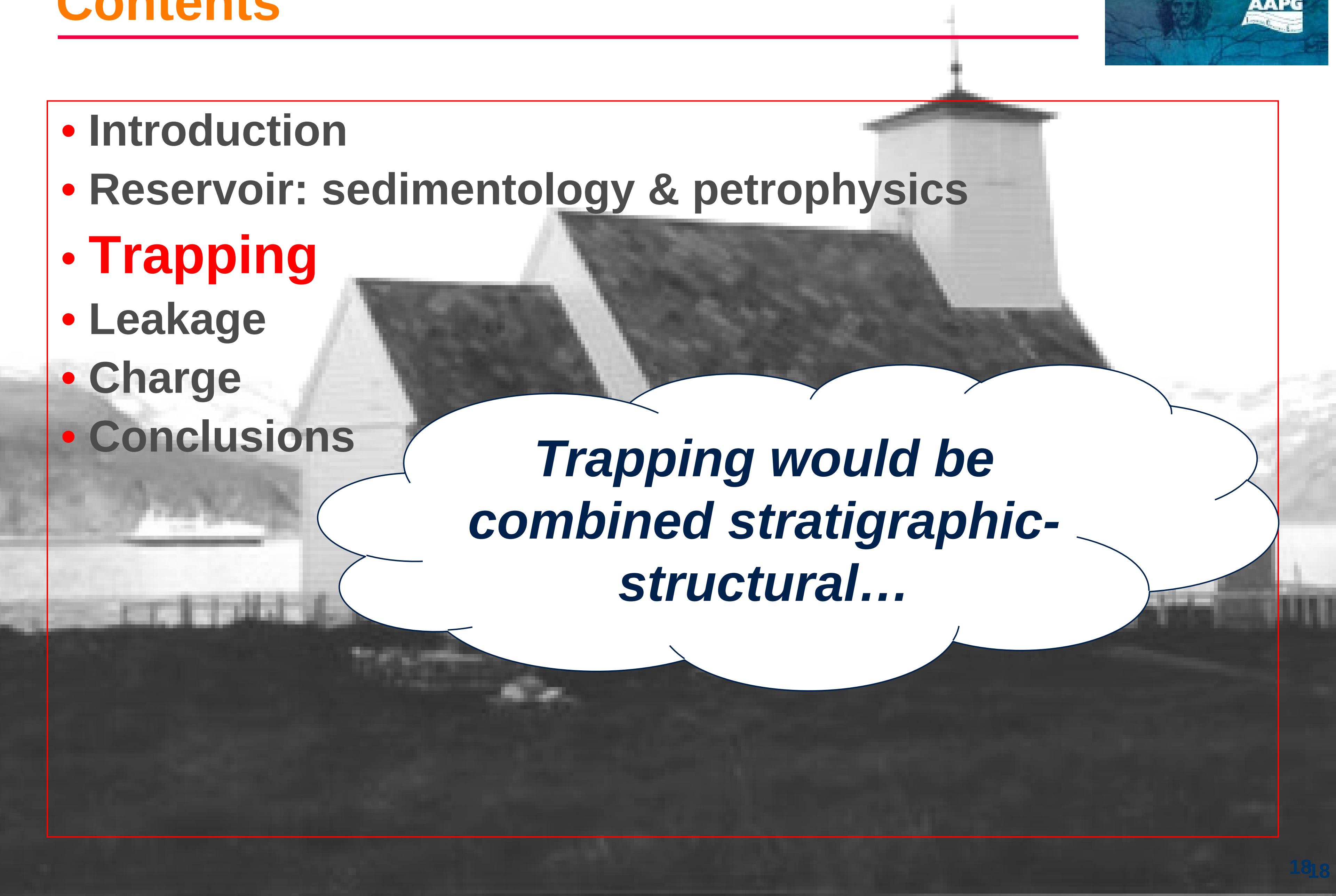

Trapping would be combined stratigraphic-structural…

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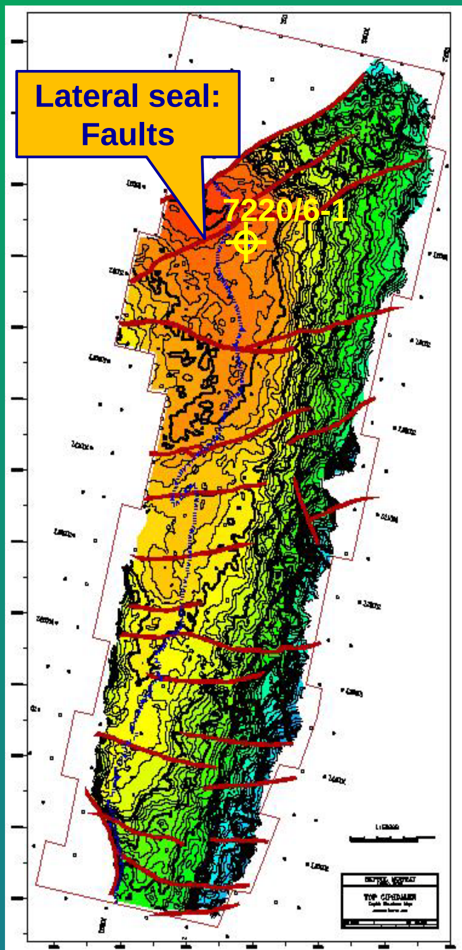
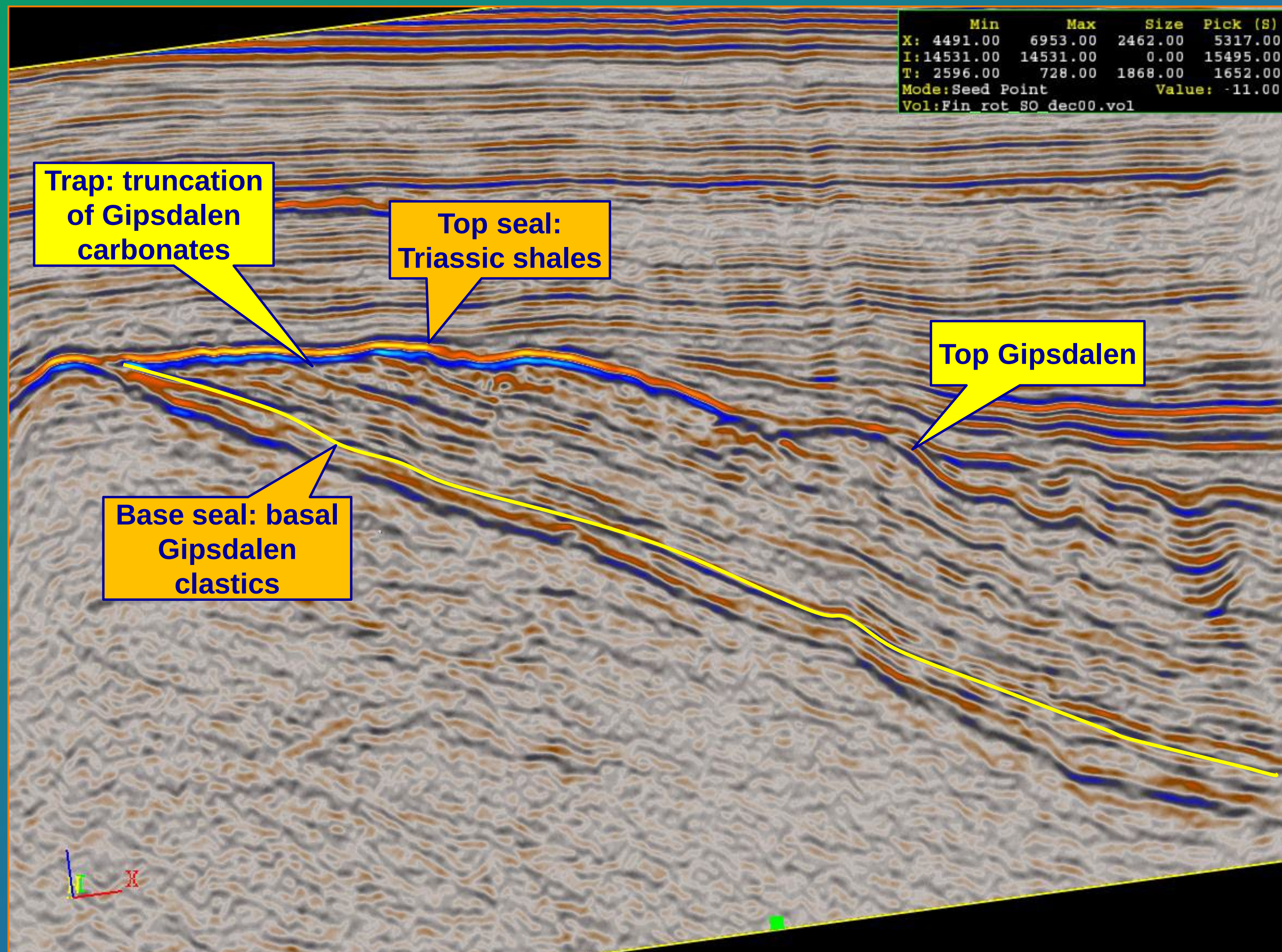
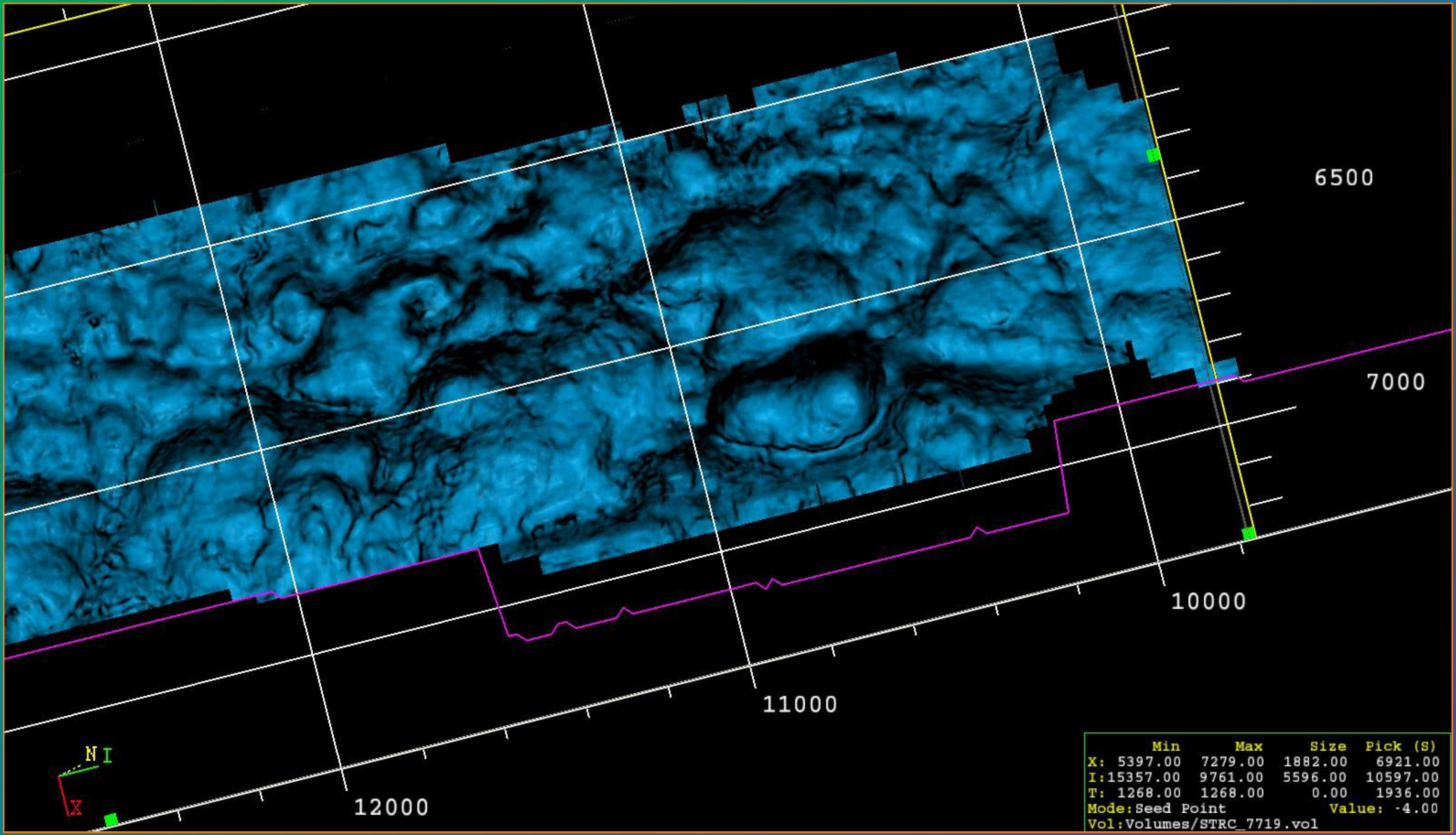
Trapping mechanism: Structural-stratigraphic

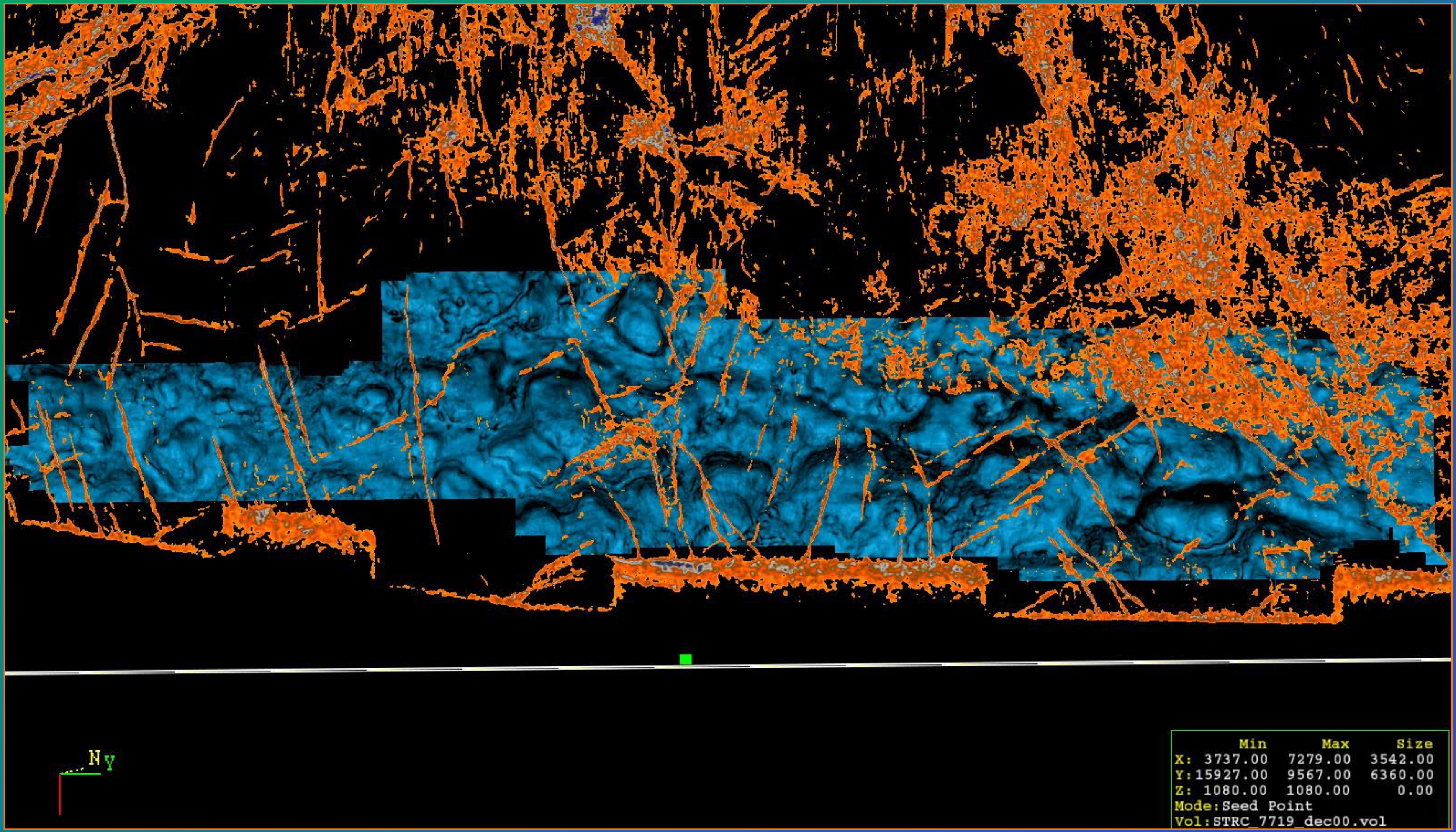




Buildups at top Gipsdalen look attractive, but are not isolated structures.



Faults required as lateral seal for buildups



Horizon shown: Top Gipsdalen
Fault pattern shown at 1080 ms

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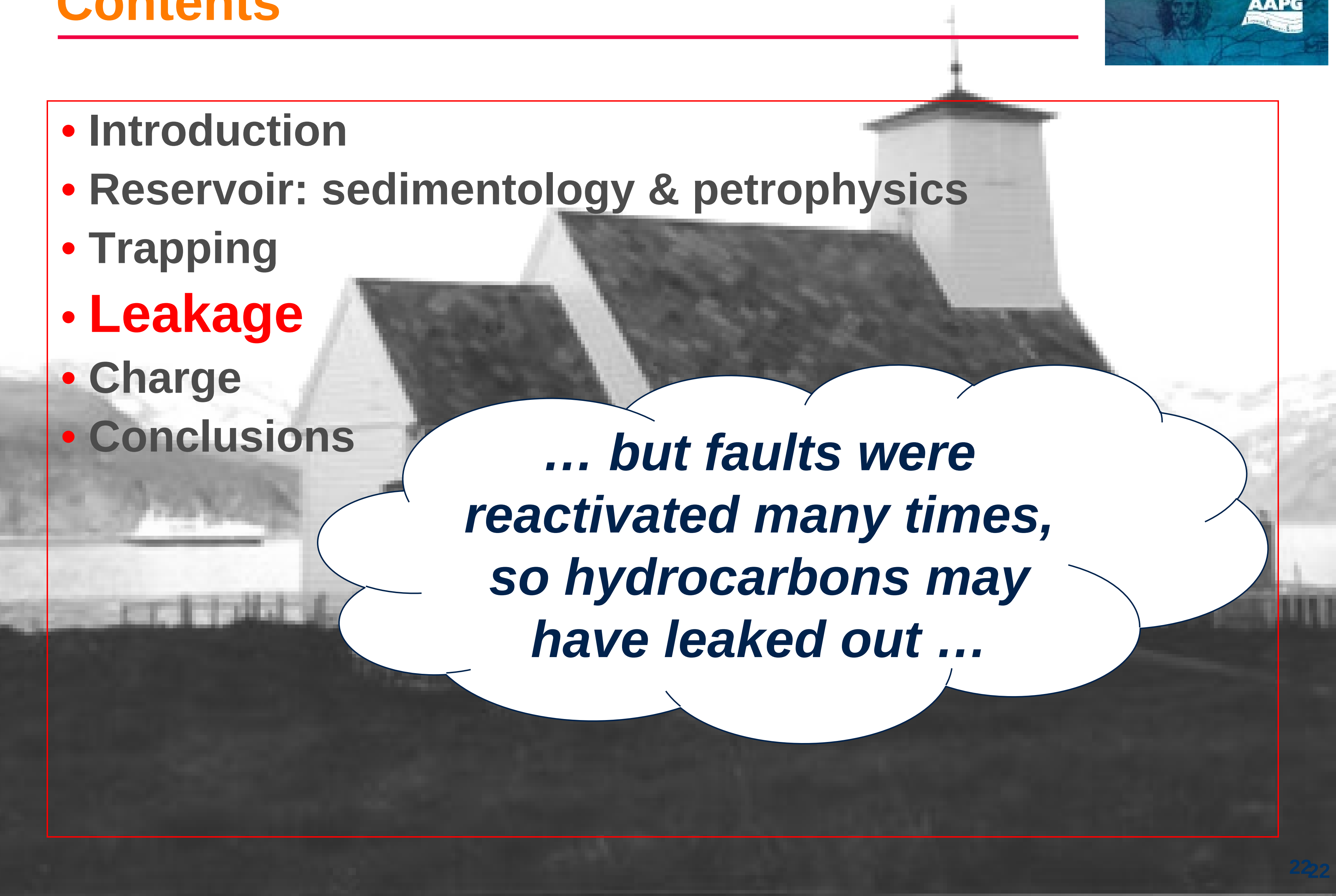

… but faults were reactivated many times, so hydrocarbons may have leaked out …

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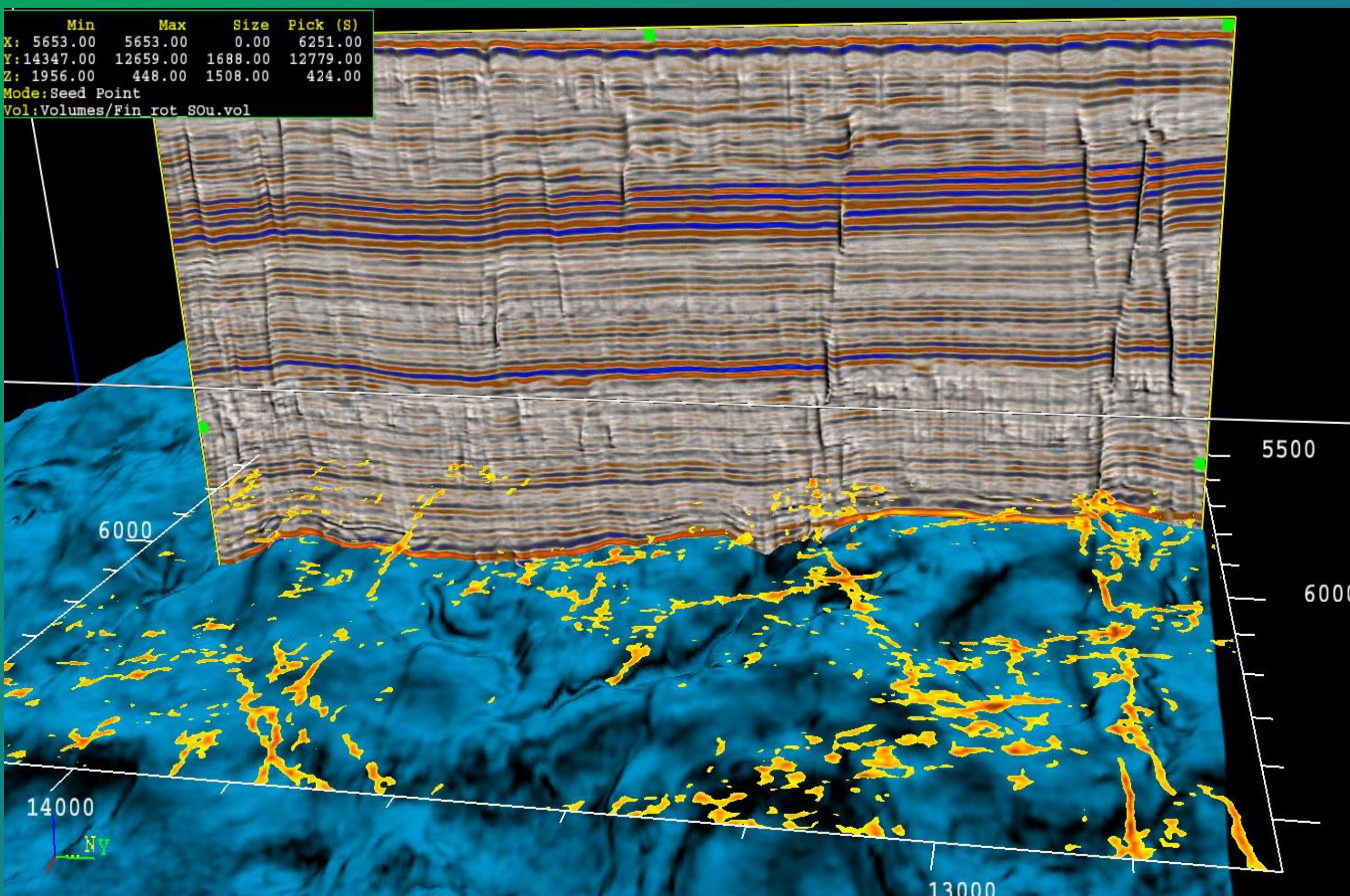
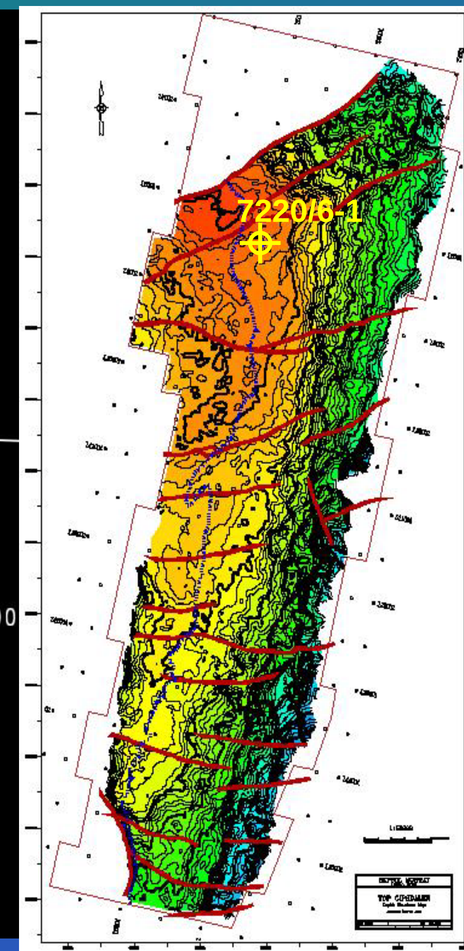
Main faults extend up to base Quaternary

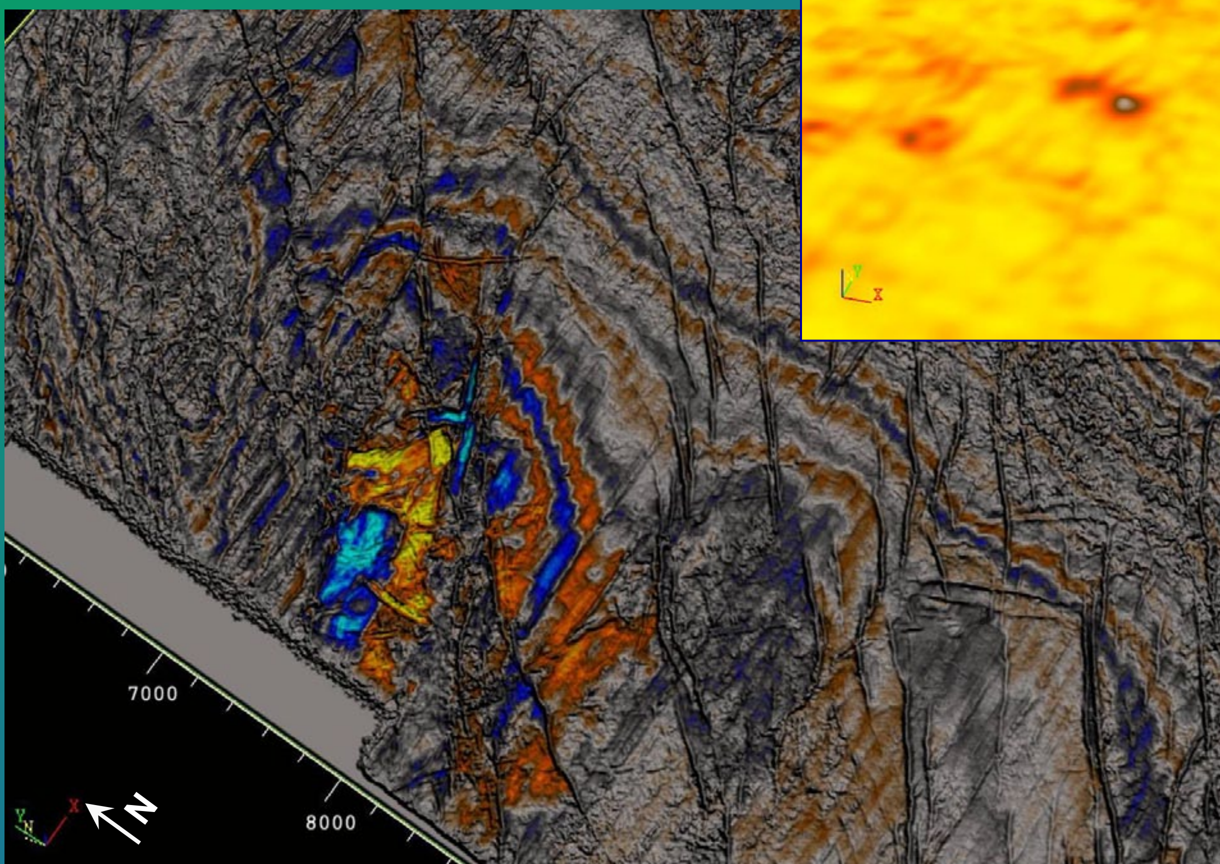


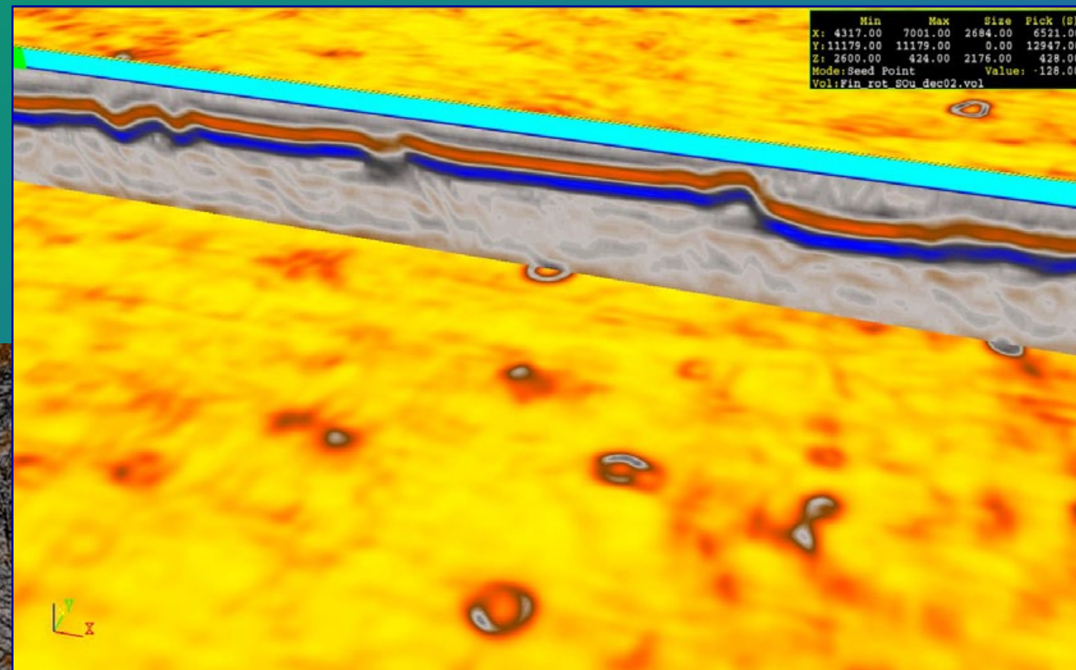


Integrated display using semblance + amplitude to highlight how faults extend upward to base Quaternary .

Leakage
Triassic: amplitudes & paleo-pockmarks

Time slice through Triassic showing high amplitude related to faults

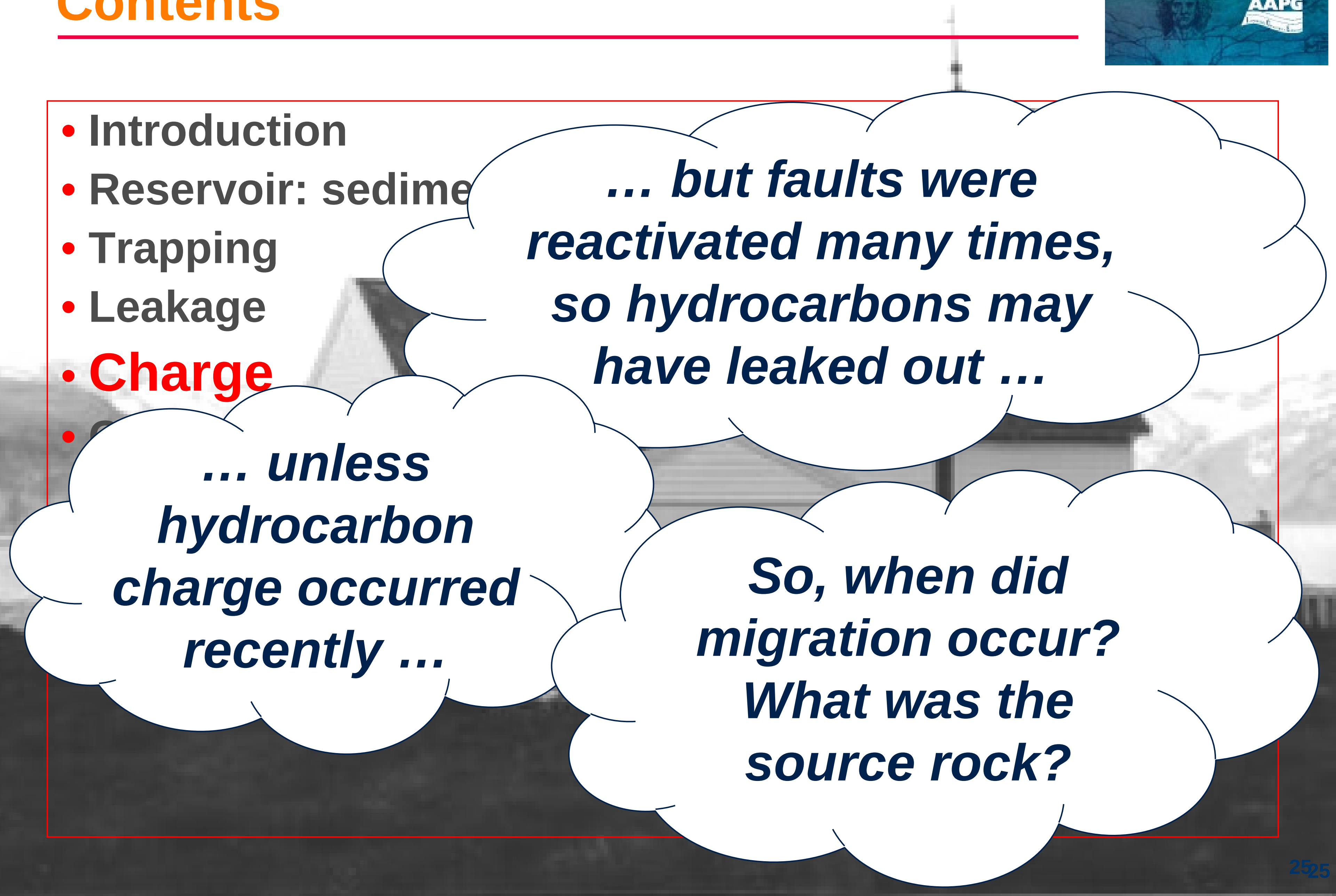




Paleo-pockmarks at Top Triassic

Semblance + amplitude

Contents



… but faults were reactivated many times, so hydrocarbons may have leaked out …

… unless hydrocarbon charge occurred recently …

So, when did migration occur? What was the source rock?

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Well 7120/2-1 Petroleum Geochemistry
Oil & rock-extract mass fragmentograms

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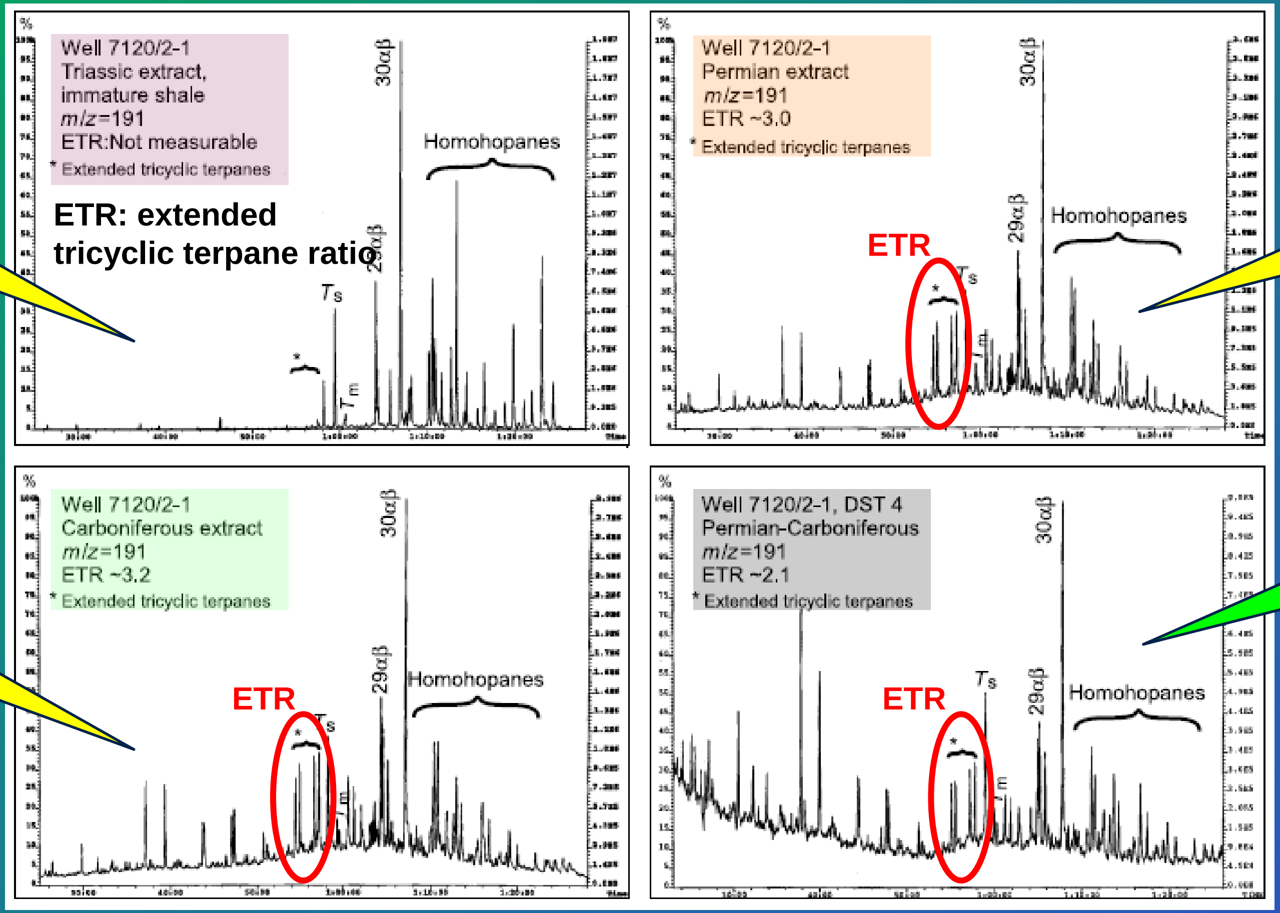
Rock extract

Rock extract

Rock extract

Oil sample

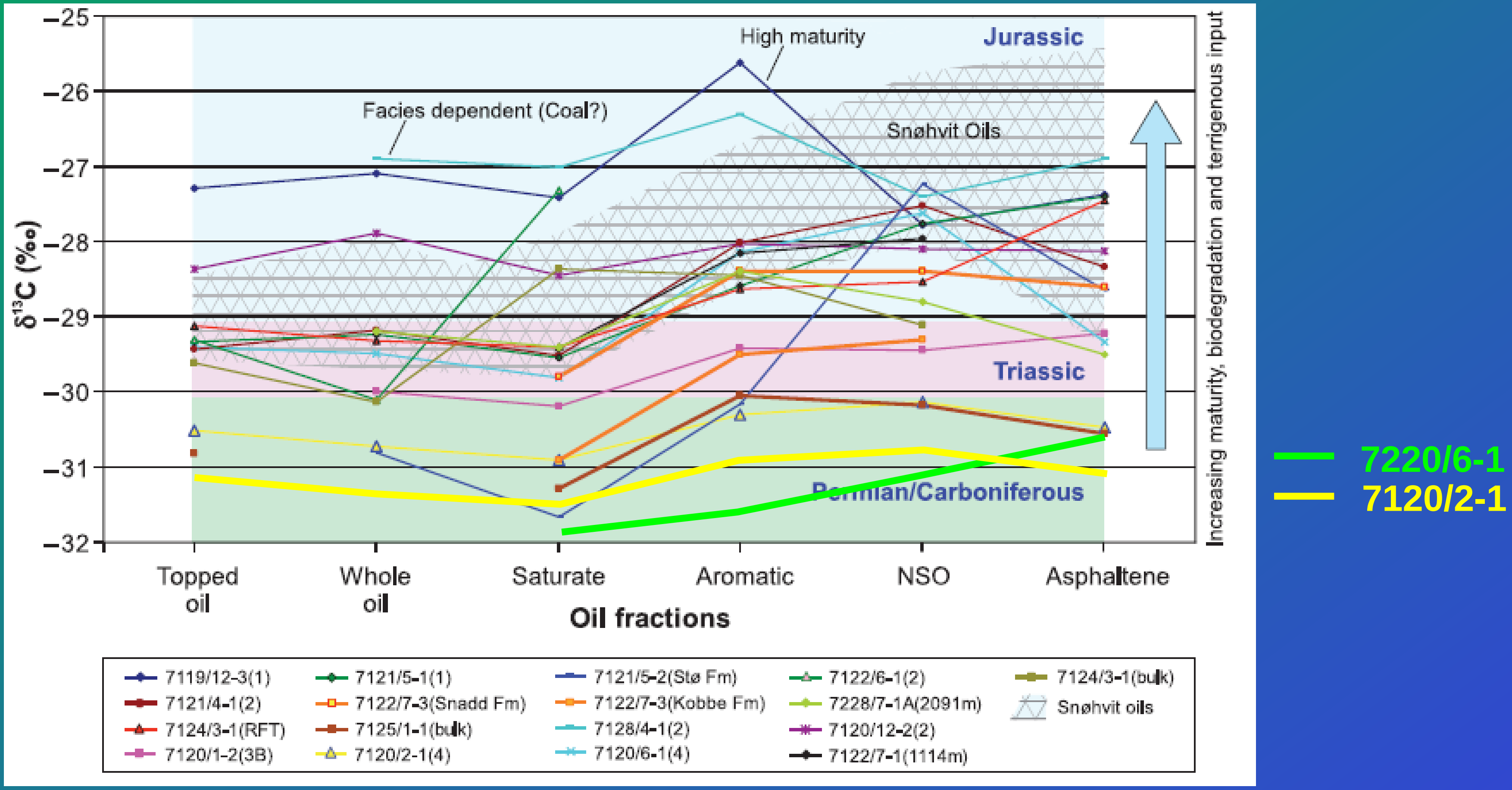


Ohm *et al*., 2008

- ✓ ETR = extended tricyclic terpane ratio. ETR > 2 indicates Triassic or older source rock.
- ✓ Oil sample shows <u>ETR of 2.1</u>, and ETR pattern is similar to Paleozoic rock extracts while Triassic extract is immature.
- ✓ Oil source is Triassic or older, most likely pre-Triassic.

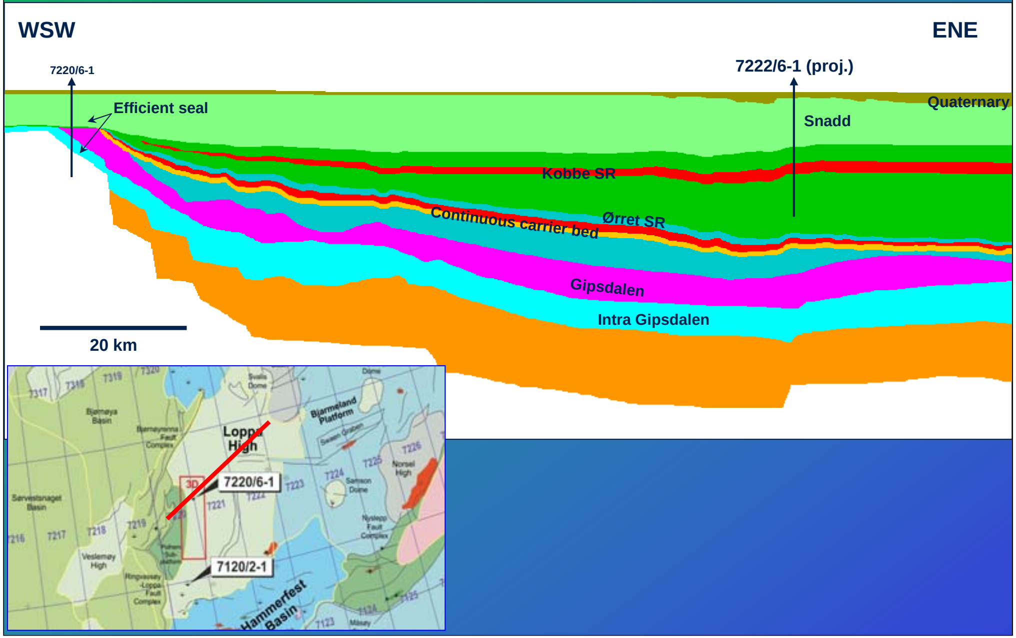
Geochemistry
Loppa High oils have no Jurassic source

The light isotopic signatures of 7120/2-1 and 7220/6-1 oils are in agreement with a possible Pre-Triassic origin



Modified from Ohm *et al*., 2008

Basin modeling



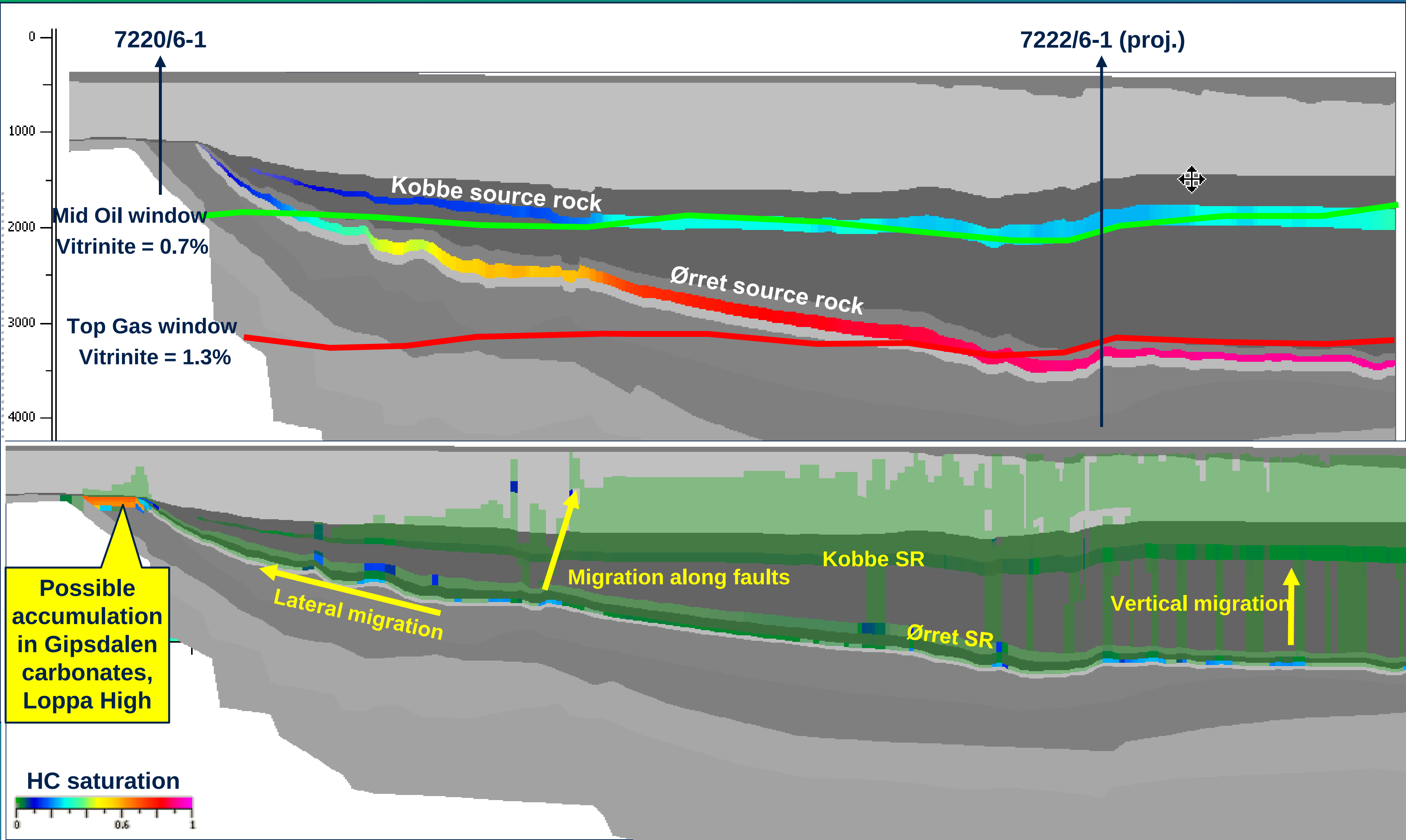
Presenter's notes: We ran a 2D migration simulation and the only way to get a commercial accumulation in the prospect was to consider the following favorable case:

-The Orret formation as the prospect's source rock.

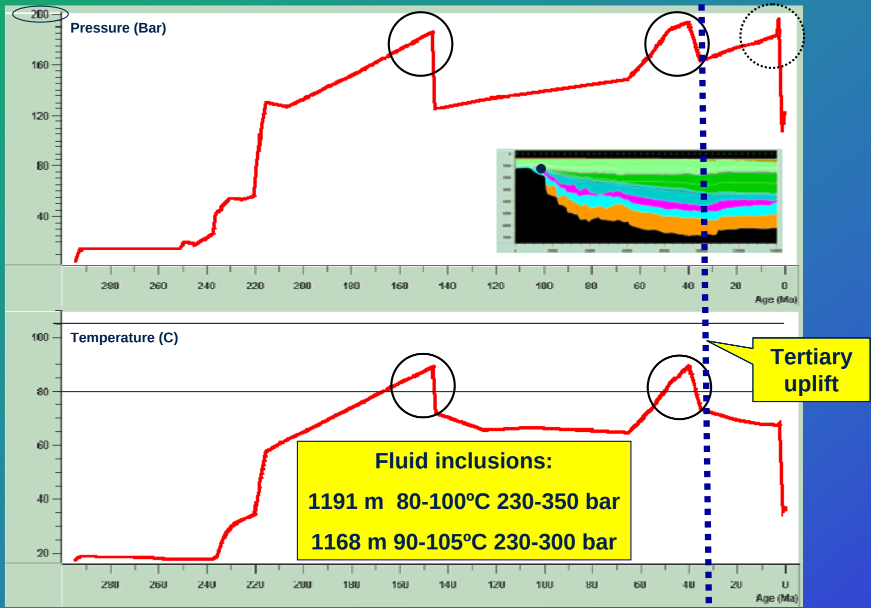
-A very good seal that resists strong pressure changes due to erosion.

-A good and continuous carrier bed below the Orret source rock that drives hydrocarbons from mature source rock, at least 30 to 40 km away, to the reservoir. Chances of migration losses are very important.

Source rocks
Kerogen transformation ratio at present day



Fluid inclusions
Combining fluid-inclusion PVT with T&P histories



Presenter's notes: In the Obelix (7220/6-1) well, oil inclusions were taken from fractures of the Gipsdalen reservoir. They indicate a trapping temperature of 80-105 ºC and a pore pressure of 230-350 psi. These results are in good agreement with the 2D model calculations for this reservoir at 40 Ma; that corresponds to the maximum burial, although pressures are slightly lower.

This can be explained by the fact that:

-the 2D basin modeling simulations do not account for the gas-column-related pressure, or

-the glaciation event generated overpressure during a short period of time.

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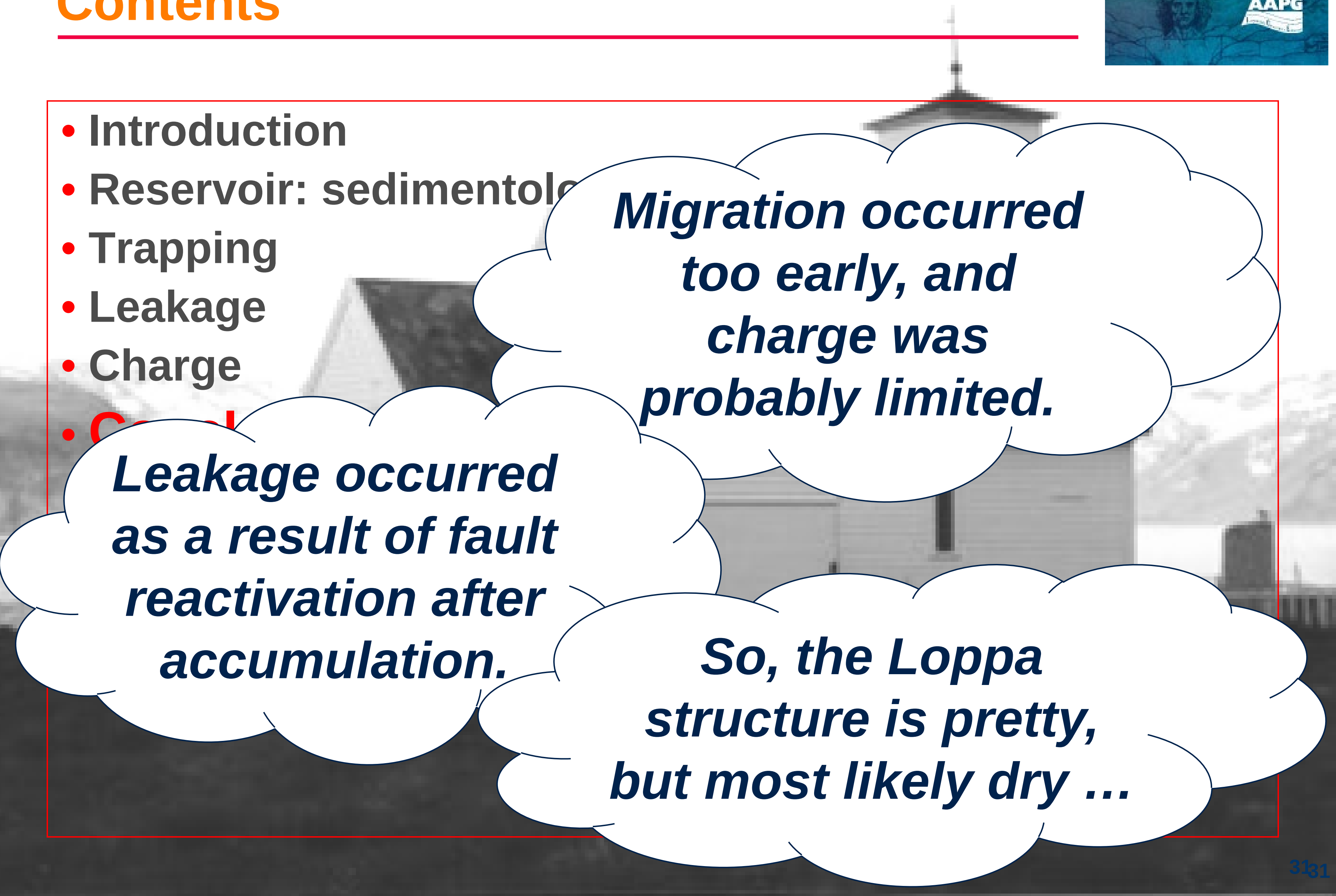

Migration occurred too early, and charge was probably limited.

Leakage occurred as a result of fault reactivation after accumulation.

So, the Loppa structure is pretty, but most likely dry …

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THANK YOU

We acknowledge:
Det norske Oljeselskap (especially Geir Elvebakk and Kai Hogstad), for many fruitful discussions
Fugro, for permission to show the regional seismic line
Repsol, for giving us permission to present this paper