Geochemically Driven Exploration Models in Uplifted Areas: Examples from the Norwegian Barents Sea*

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Abstract

The Norwegian Barents Sea with multiple source rock intervals represents a prime example of an overfilled petroleum system. However, several episodes of uplift and erosion from the Paleocene until the Plio-Pleistocene have caused depletion of hydrocarbon accumulations in the region. It is important to realize that these uplift events were not only potentially catastrophic but have also caused the redistribution of the remaining oil and gas over laterally large distances in the Barents Sea region. This redistribution directed petroleum to distal parts of the various hydrocarbon generating basins, thus charging traps, which otherwise would not have been reached. It is therefore, to be expected that discoveries will be made in distal basin settings, particular in traps with partly leaking cap-rocks which can bleed-off gas and thereby retain oil. Many oil accumulations in the region represent various mixtures of oils from a number of different stratigraphic source intervals. This suggests that Triassic and Paleozoic oils may be trapped below the presently drilled targets, which are mostly of Jurassic age in the Hammerfest Basin and older to the north and eastwards. Deeper exploration targets also stand a higher chance of containing oil as the amount of gas being released from oil during uplift, erosion and subsequent pressure release is lower. Uplift and erosion is followed by a reduction in temperature. This is why hydrocarbon generation is believed to have ended in uplifted areas. Some discoveries in this dataset suggest, however, a significant fresh gas charge.

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Geochemically driven exploration models in uplifted areas:

Examples from the Norwegian Barents Sea

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Oil is likely to be found on the flanks of basins with partly leaking seal

The pre-uplift history of the sedimentary basin is instrumental for preserving oil

Most of the discovered oils represents mixtures/coctails of petroleum from various SR intervals, thus potential deeper reservoir targets may be charged

Strong circumstantial evidence for live petroleum system

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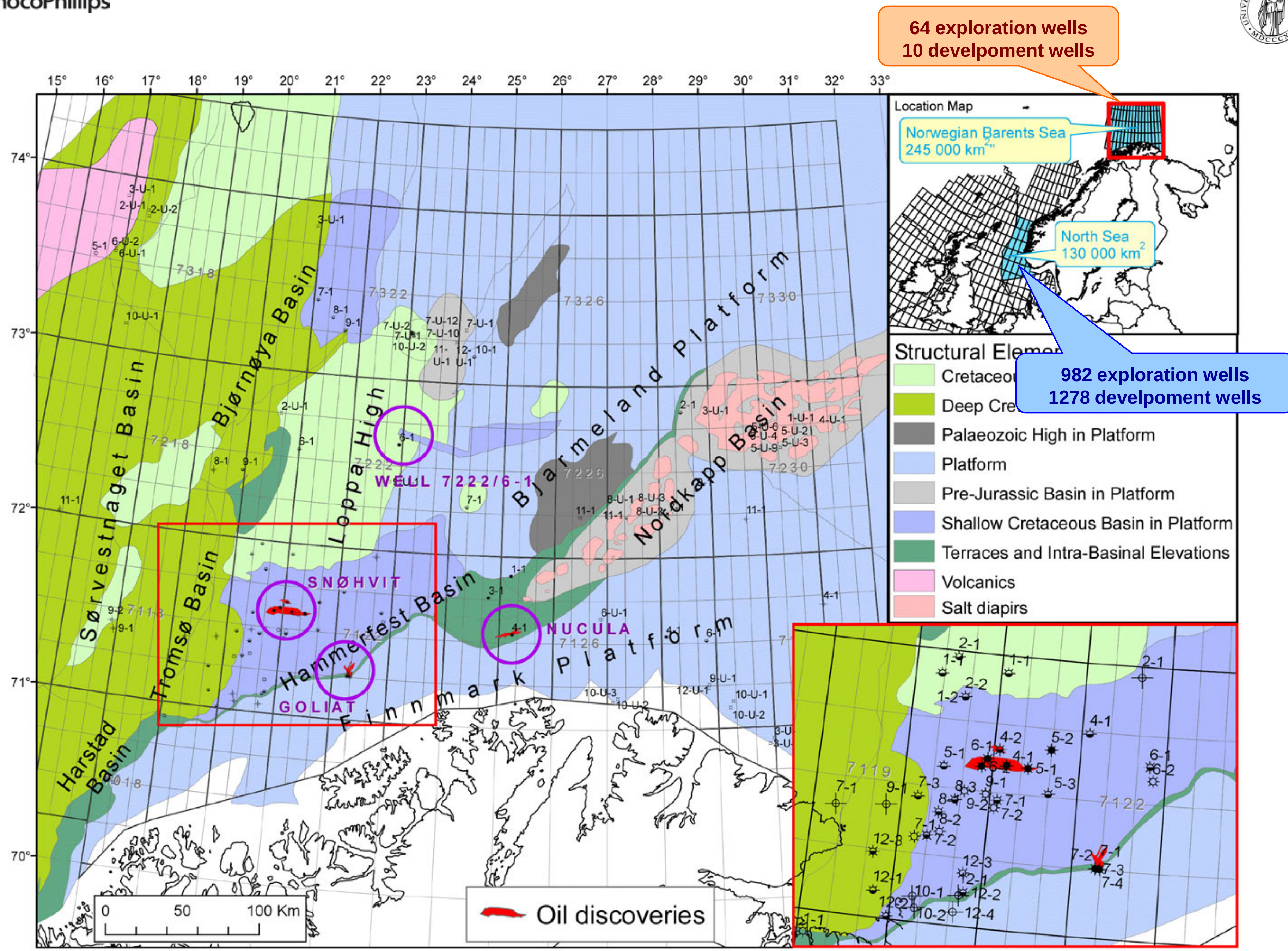
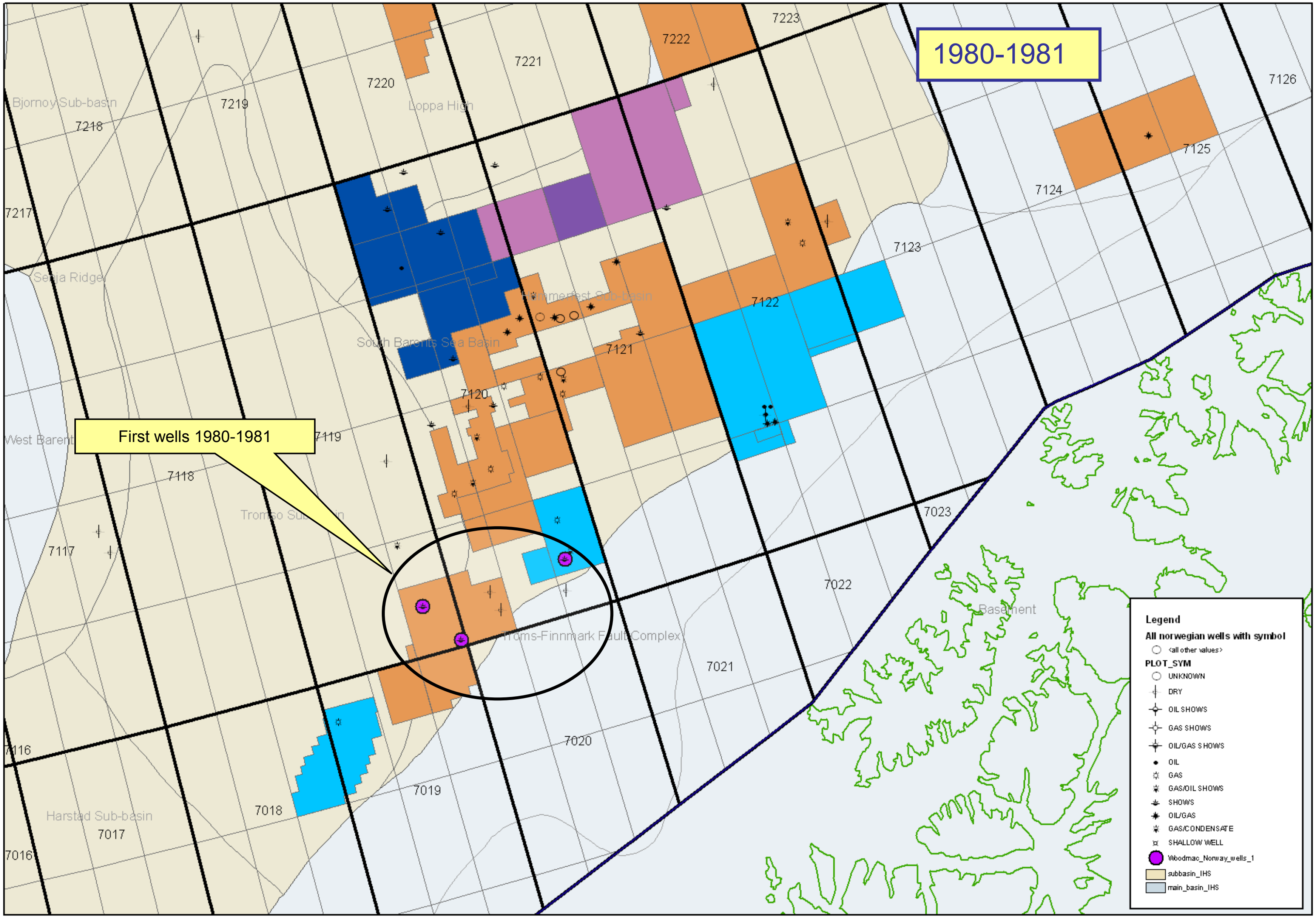
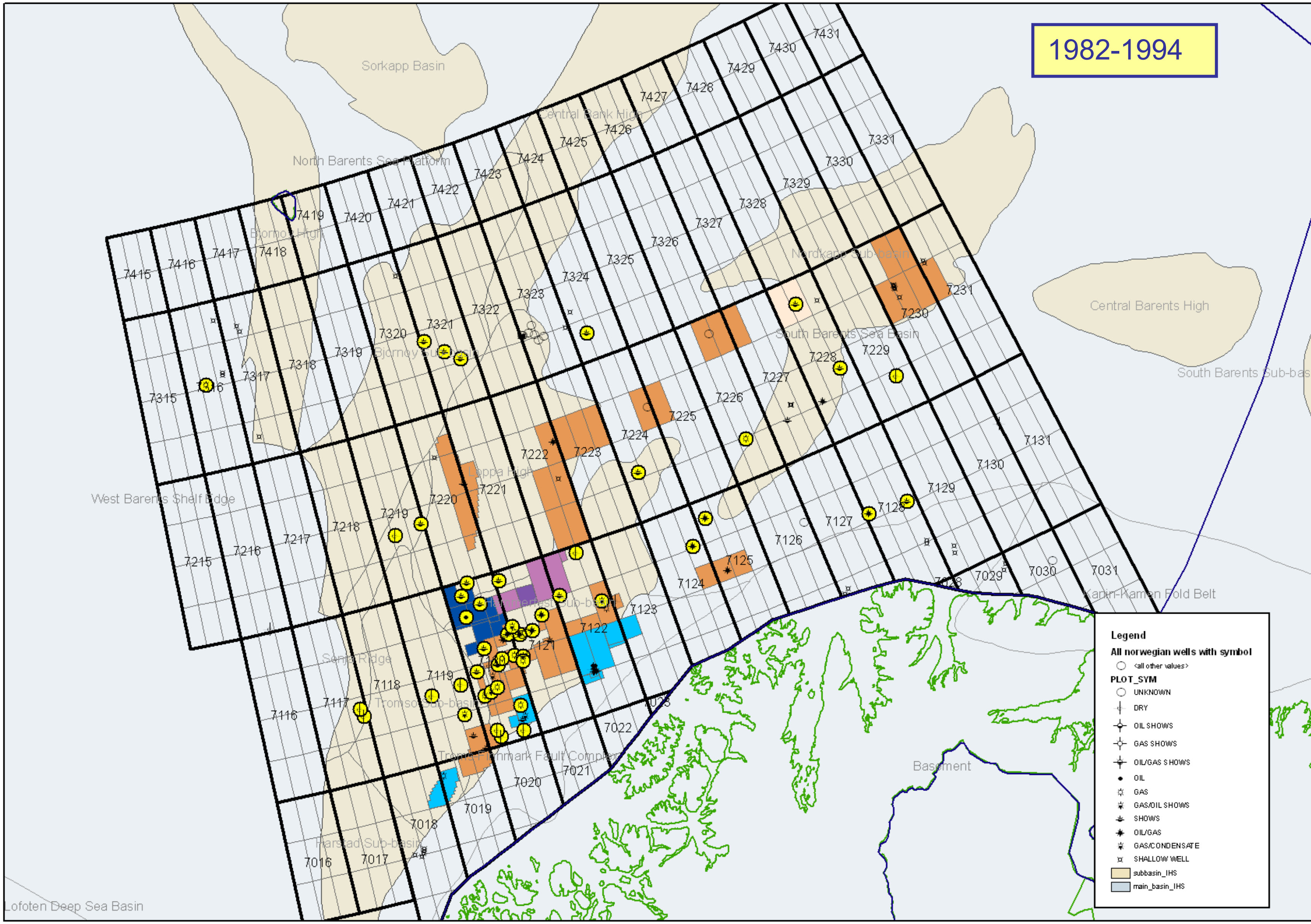


Barents Sea Wells



Barents Sea Wells



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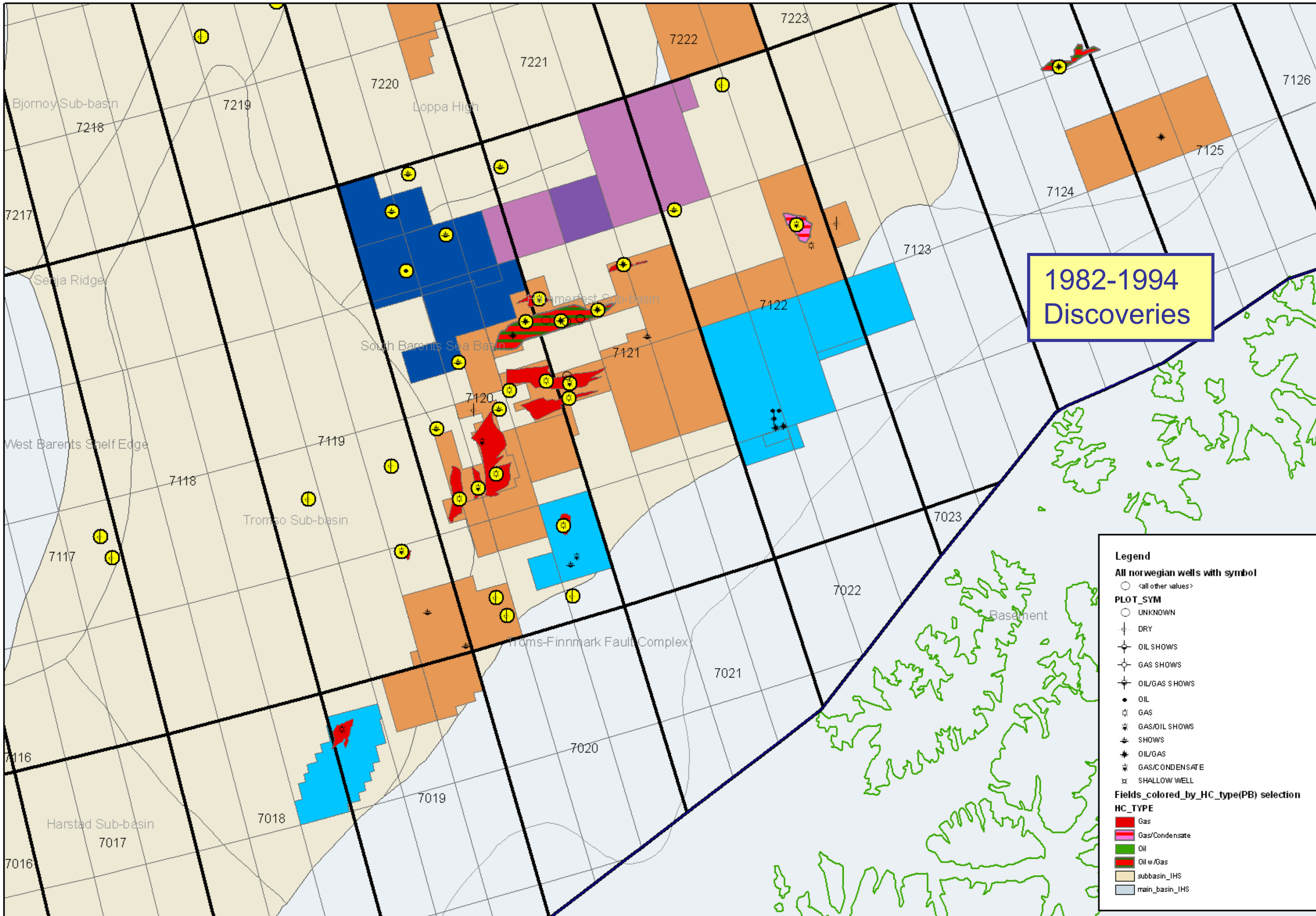
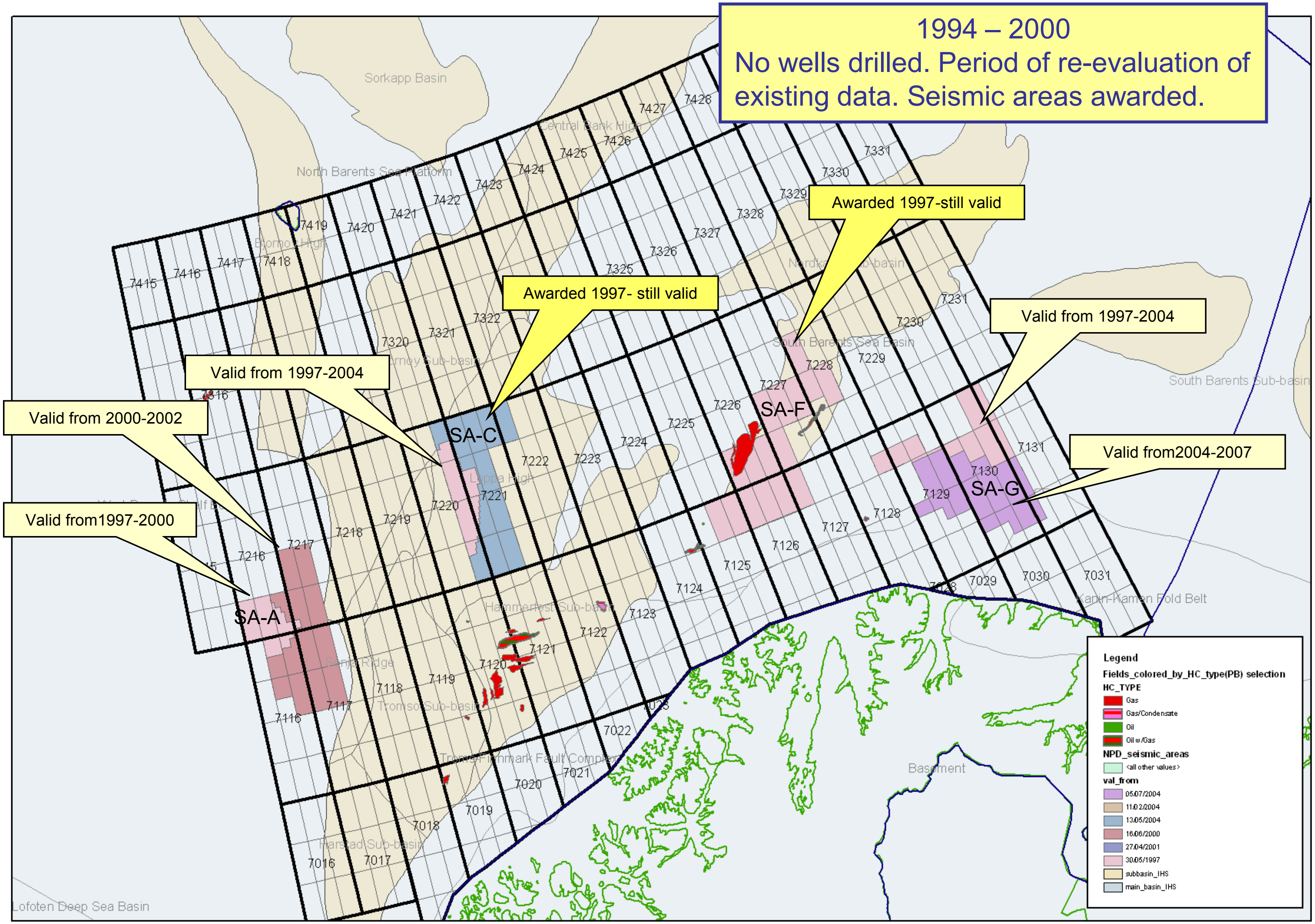
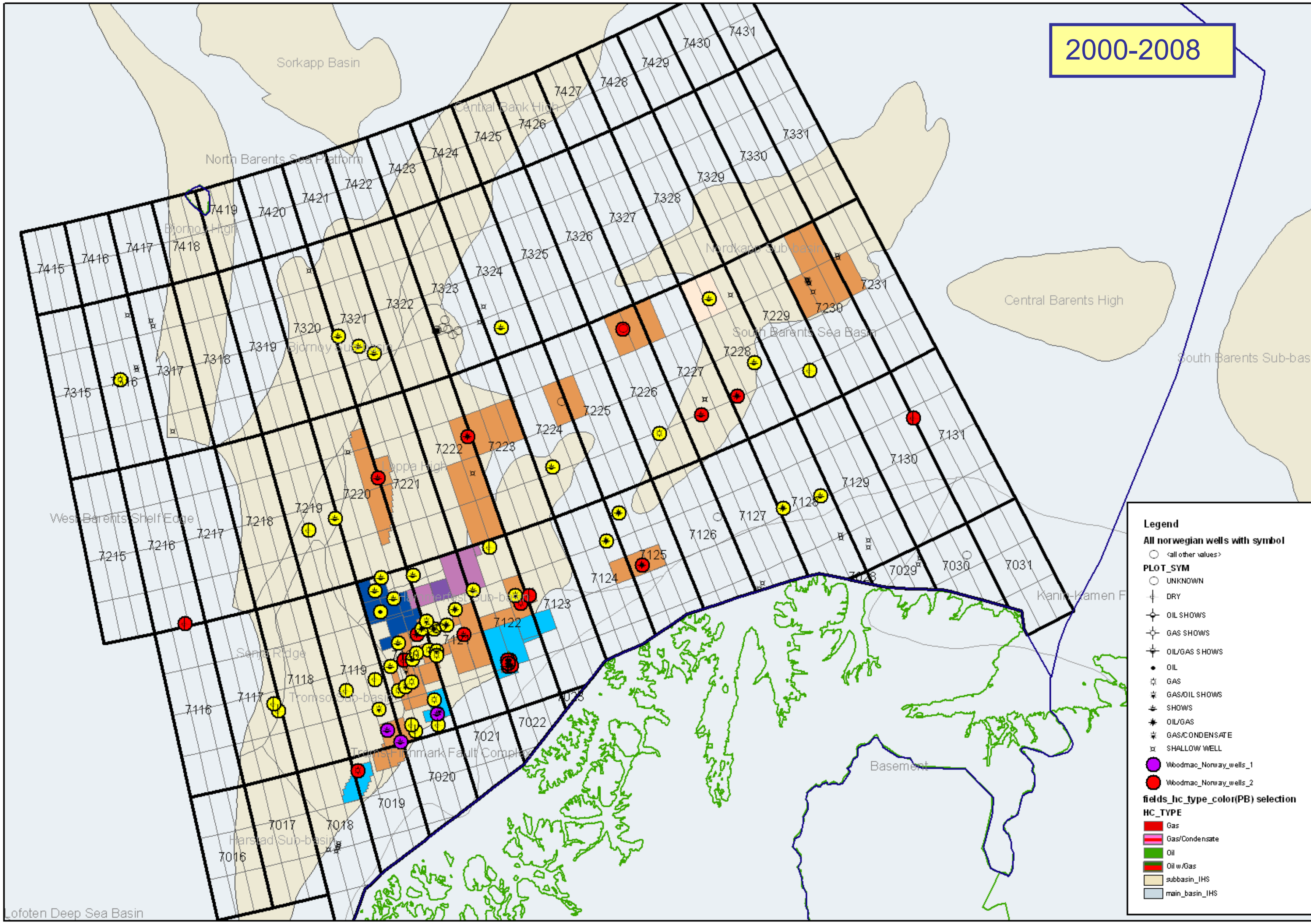
Barents Sea Wells



Barents Sea Wells



Barents Sea Wells



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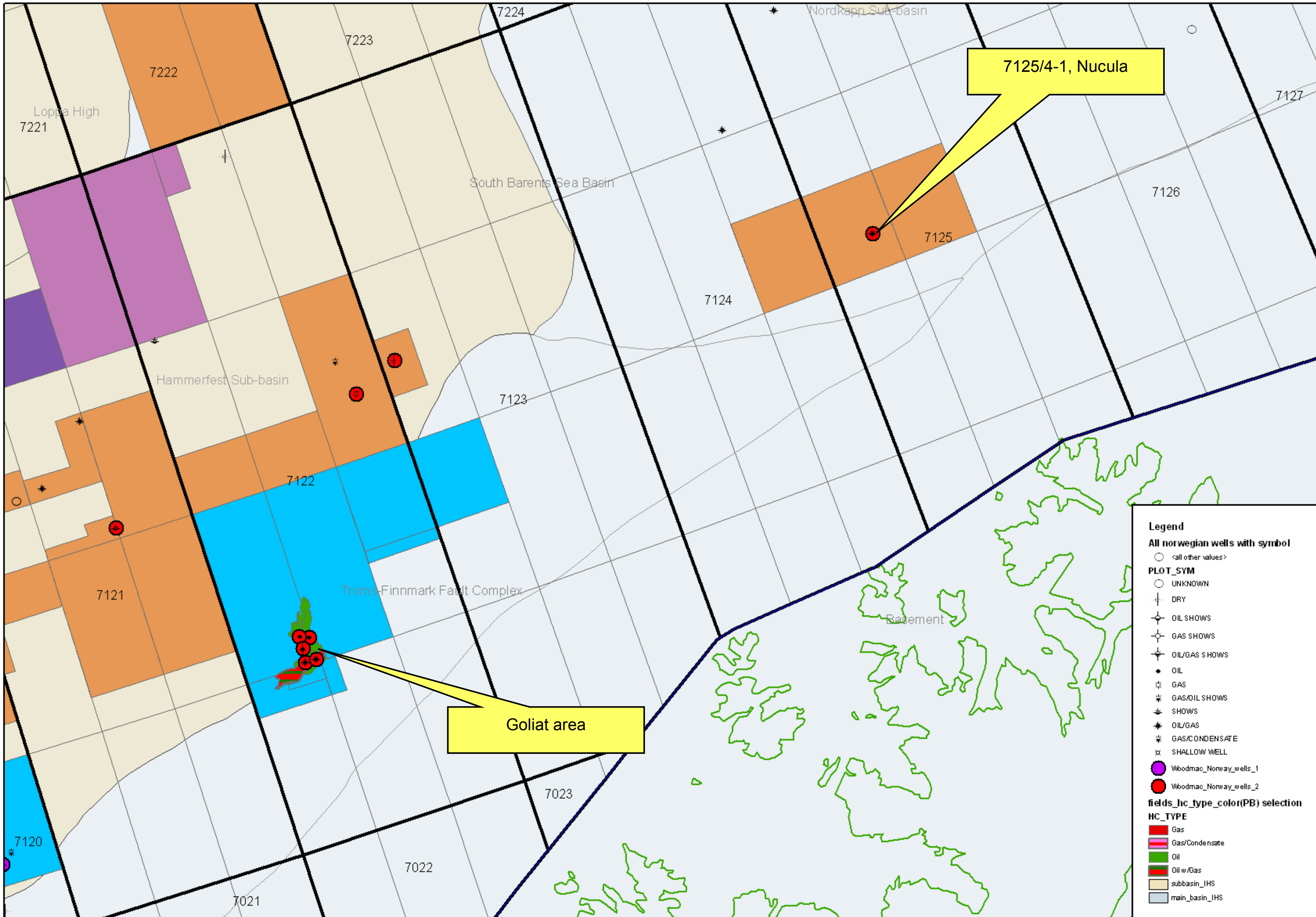
Barents Sea Wells



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The success rate in the Norwegian Barents Sea has been high with discoveries in roughly 1 of 3 wells

But,….these are mostly disappointing?

Many of the discoveries are only partly filled with gas, some of which have an oil leg.

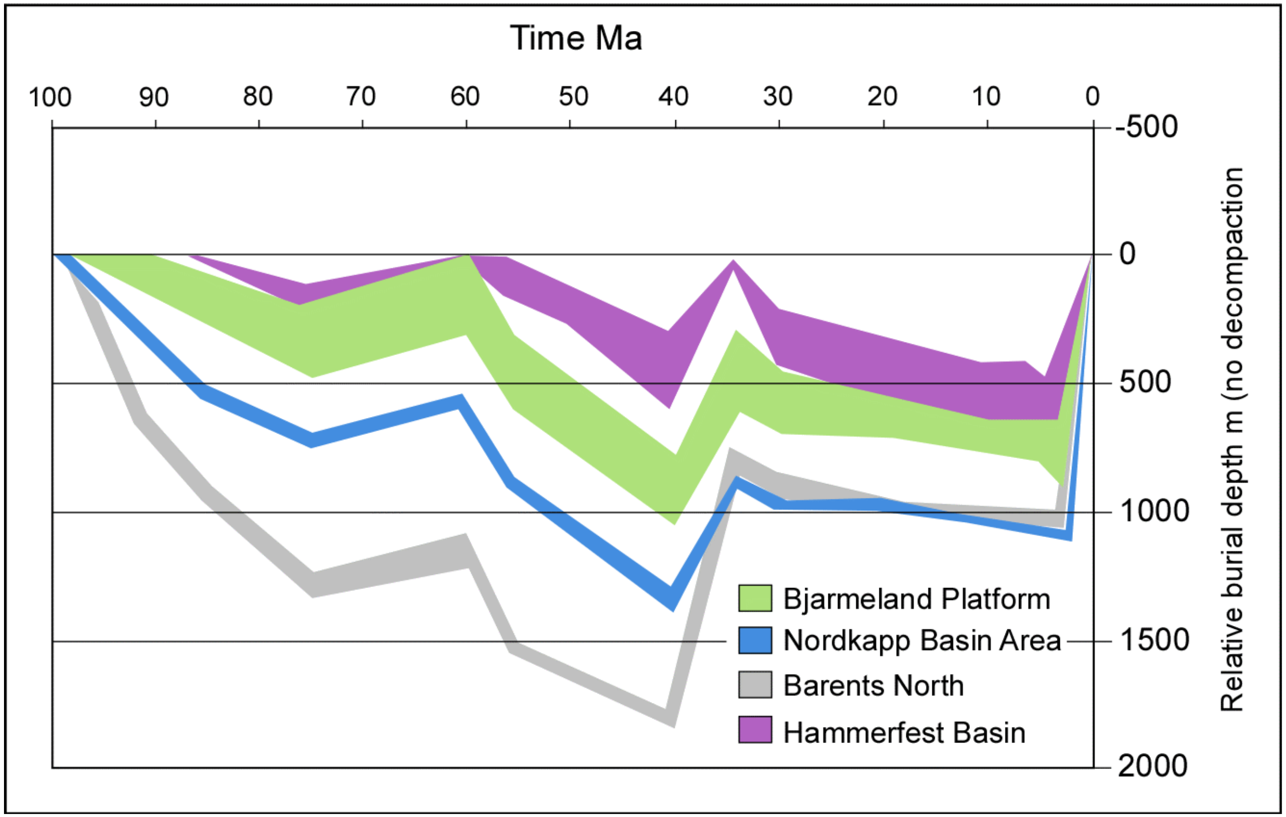
The oil-legs are normally thin, 2-10m.

Typical are structures with “dry”-non-producible gas and only residual oil saturation that may reach over several hundred of meters (i.e. thick residual oil column).

Many traps have leaked and are only partially refilled with gas

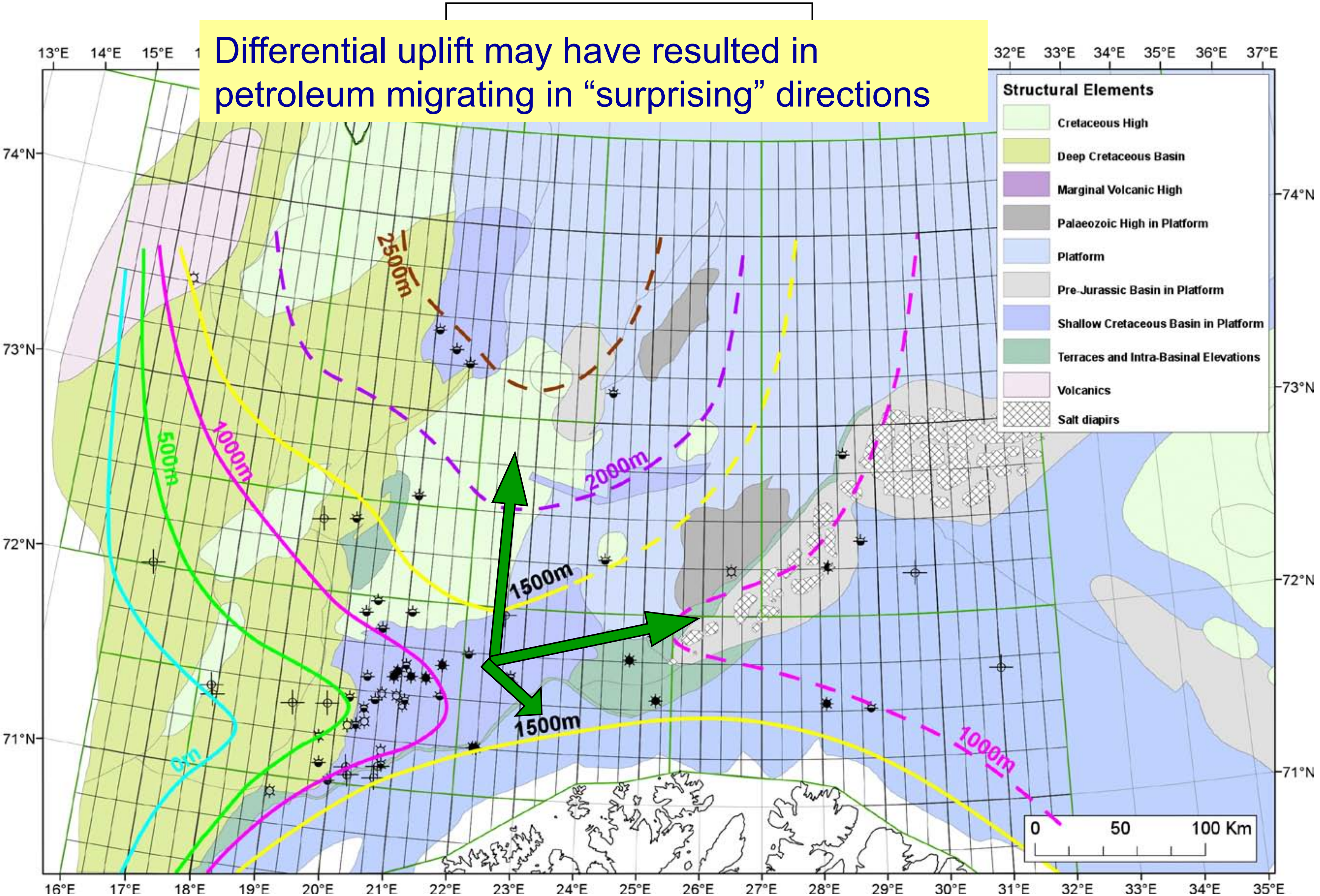
Cited reasons for failures

Pressure release in the reservoirs following uplift and erosion resulted in oil accumulations becoming di-phasic. Further pressure release resulted in gas expansion, which subsequently forced oil below the spill points *(Nyland et al., 1992).*



Cited reasons for failures

Differential uplift may have resulted in petroleum migrating in “surprising” directions



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Cited reasons for failures

Pressure release in the rese… il

accumul…

The Barents Sea is an oddball area among uplifted petroleum provinces, where most of the

v…

We believe that more thorough investigations of the petroleum system will generate new exploration models, which will lead to more oil discoveries in the area.

Th… s

fr… st

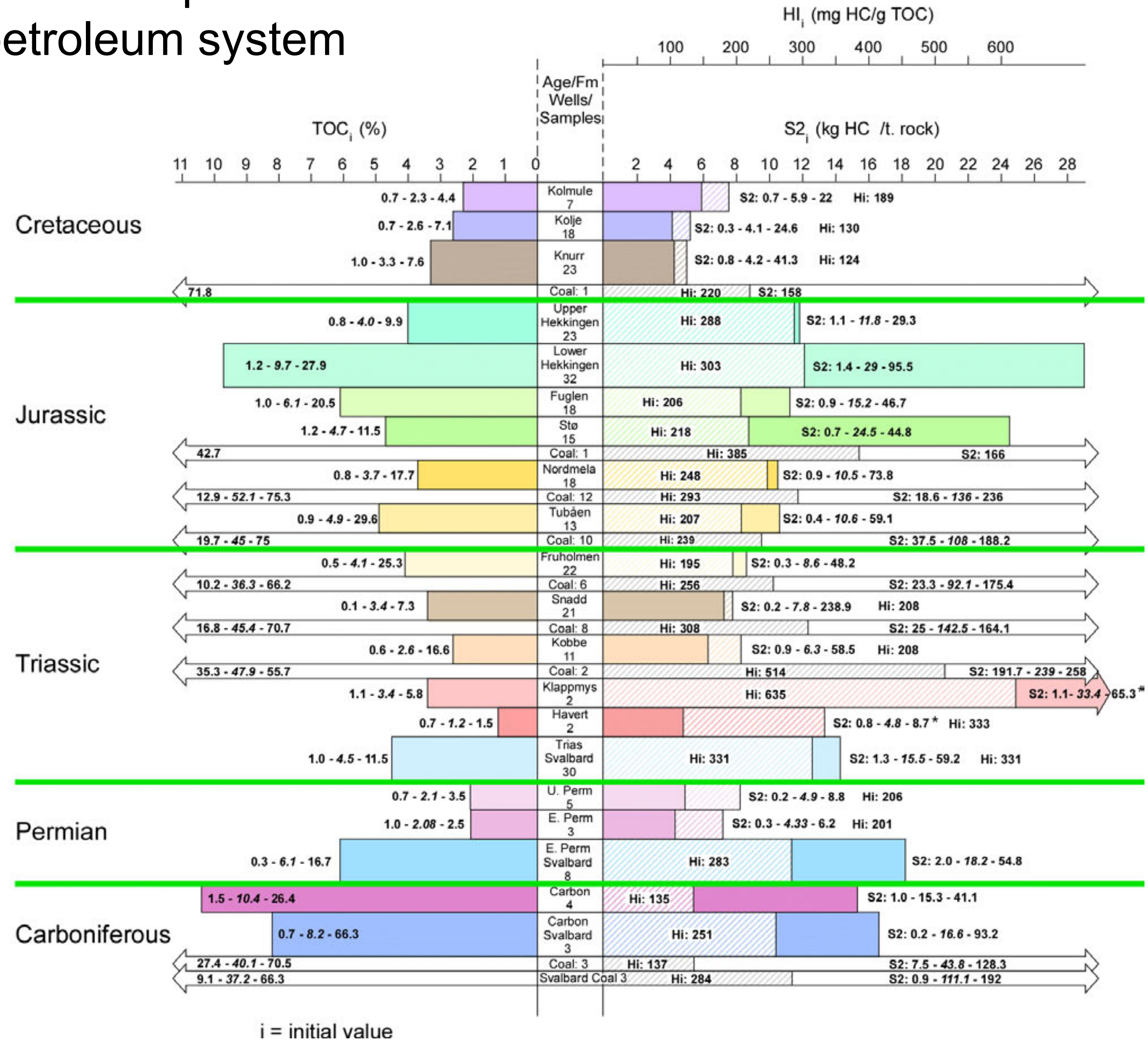
ex… potentials in

the Norwegian Barents Sea

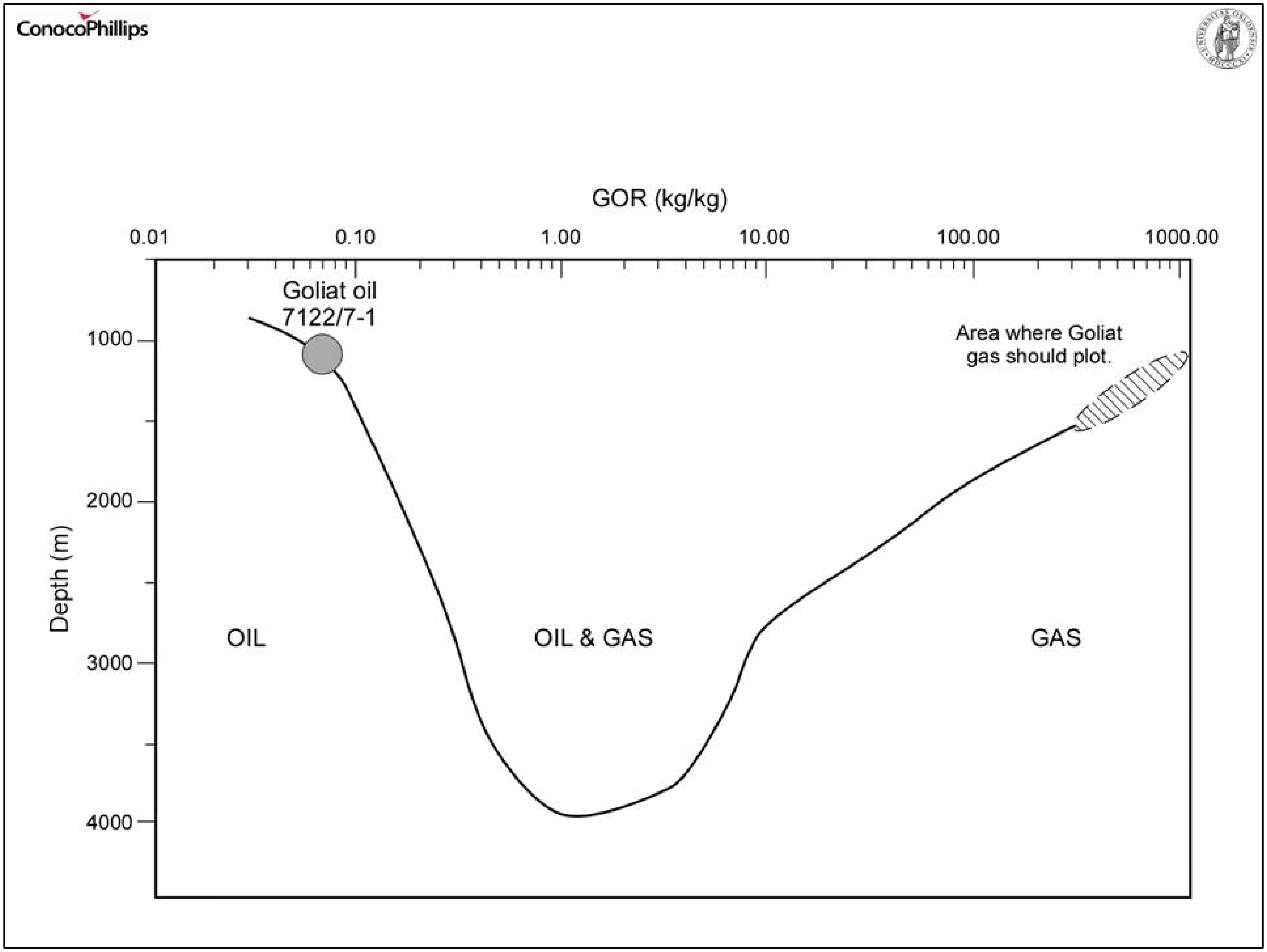
Lower reservoir quality than expected due to it having been buried deeper than present day *(Bjørlykke, 1983; Berglund et al., 1986).*

Source Rock Quality Diagram
Initial Values

The Barents Sea represents an overfilled petroleum system



Oil likely resting on the flanks of basins with partly leaking seal



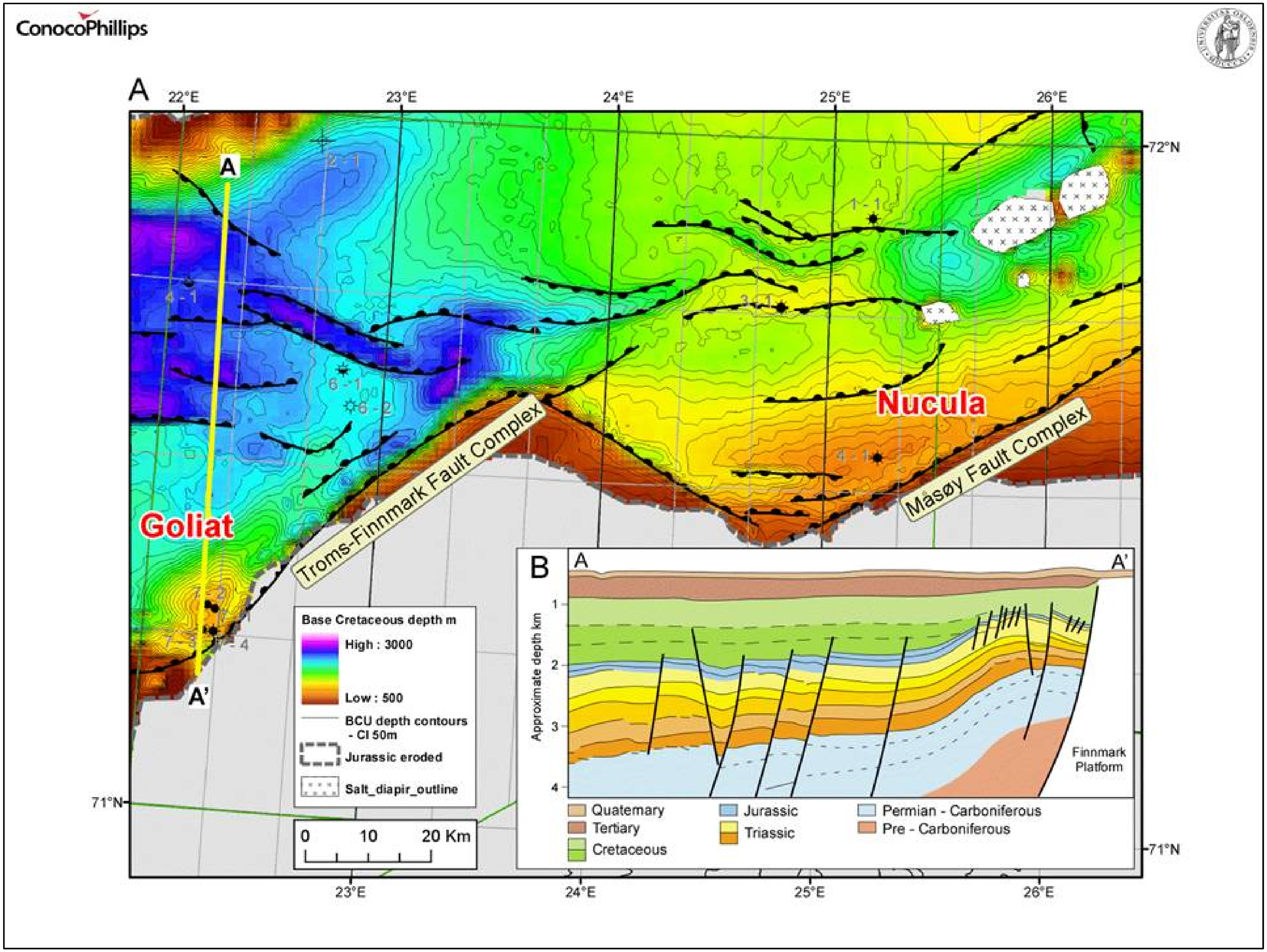
Notes by Presenter:

The Goliat oil would, however, not have released large volumes of gas if it was strongly under-saturated or if it recently migrated into the trap (post-uplift). The oil being strongly under-saturated is not a likely scenario considering all the gas found elsewhere in the Hammerfest Basin and post-uplift oil charging neither is a likely scenario given that oil generation ended during uplift and erosion. So, the question remains - where has all the gas gone?

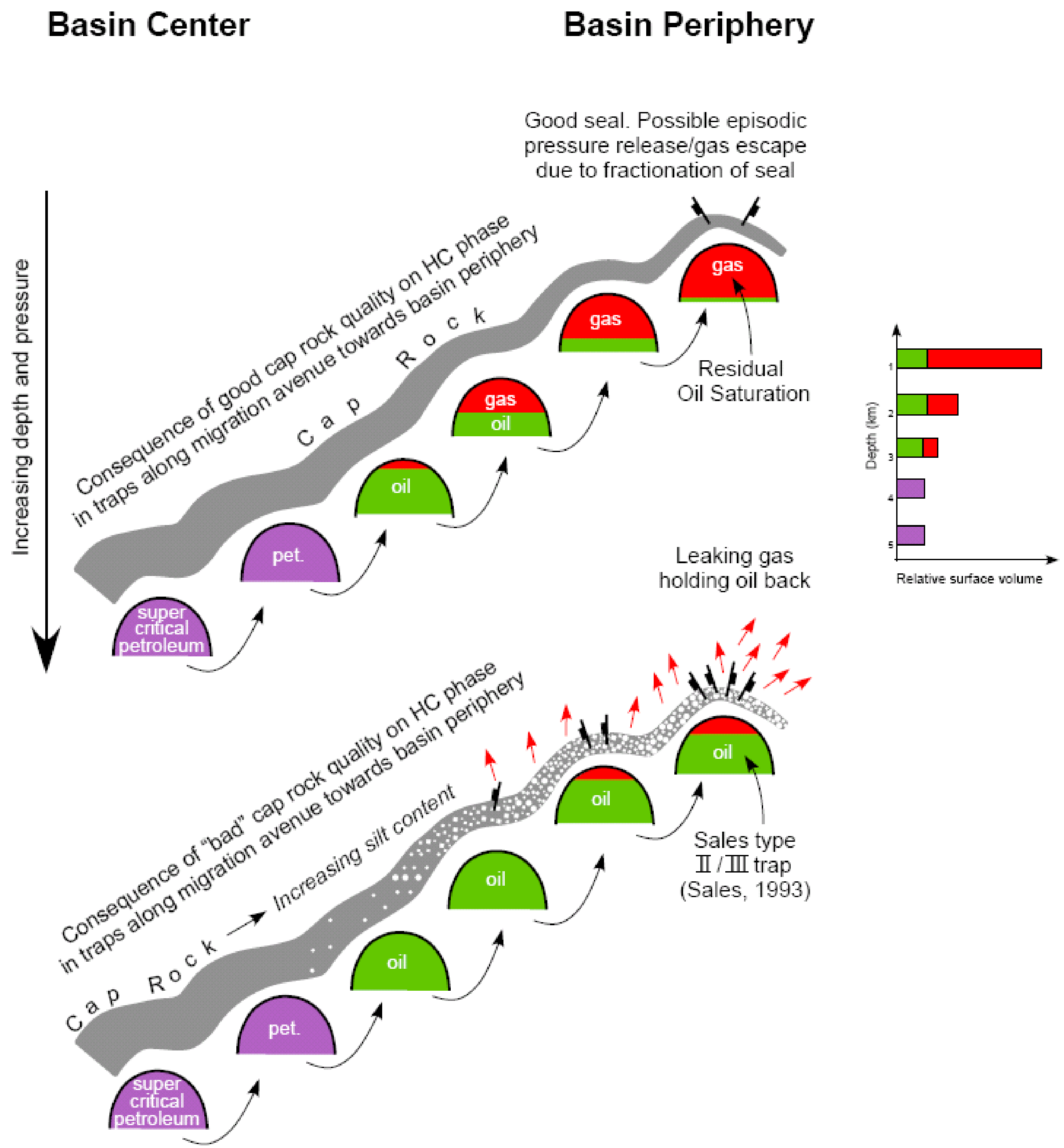
Figure 21 illustrates that oil accumulations buried deeper than ~4000m will be mono-phasic. As a consequence oil accumulations buried deeper can undergo pressure release without turning di-phasic

It is also evident that the more undersaturated the pre-uplift oil is the more uplift it can take without releasing gas. Thus, deeply buried traps and/or under-saturated oil accumulations form exploration targets, which may survive the effect of pressure release during uplift and erosion (Doré and Jensen, 1996).

Also oil accumulations, which have undergone subsidence, will at least tolerate the same amount of uplift before dissolution of gas. Consequently the pre-uplift history is instrumental for preservation of oil accumulations during uplift; GOR of initial oil, subsidence history, burial depth, and amount of uplift.

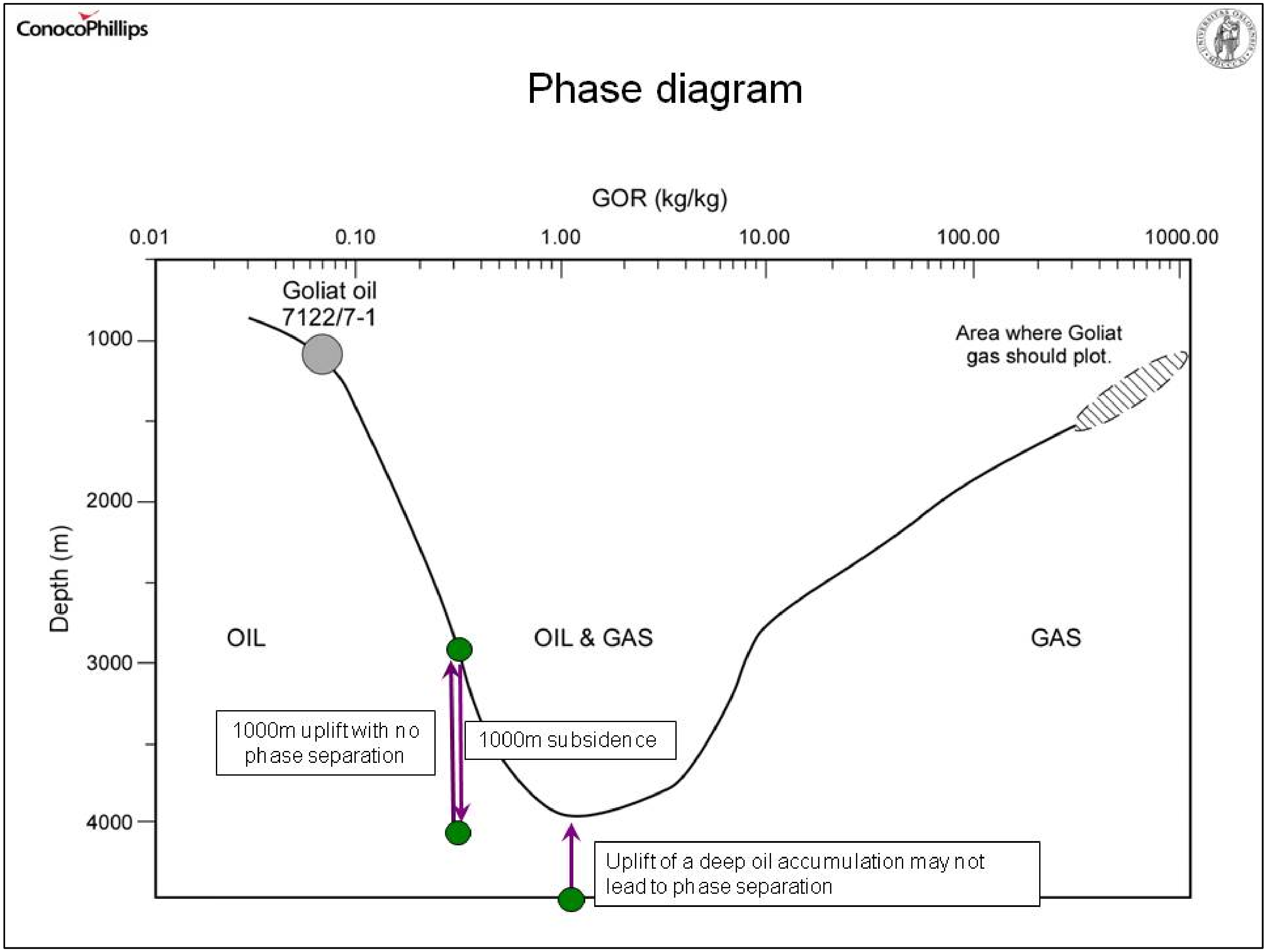


Notes by Presenter: The answer to this is possibly linked to the geology of the Goliat area. Both the Goliat and the recent Nucula discoveries are found on roll-over structures located fairly close to the fault complexes adjacent to the Finnmark Platform (Fig. 22a). These areas are extensively faulted and the top seal is bisected by numerous faults (Fig. 22b). The top seal is also thinner and more silty on the flanks of the Basin than in the center. It is for these reasons speculated that gas as elsewhere in the Basin was released from the oil during uplift and erosion, however, contrary to other known discoveries the gas escaped selectively through the partly leaking cap rock leaving the oil in the trap.



Basin Center
Basin Periphery
Good seal. Possible episodic pressure release/gas escape due to fractionation of seal
Increasing depth and pressure
Consequence of good cap rock quality on HC phase in traps along migration avenue towards basin periphery
C a p R o c k
gas
gas
gas
oil
oil
pet.
super critical petroleum
Residual Oil Saturation
Depth (km)
Relative surface volume
Leaking gas holding oil back
Consequence of "bad" cap rock quality on HC phase in traps along migration avenue towards basin periphery
Increasing silt content
C a p R o c k
oil
oil
oil
oil
pet.
super critical petroleum
Sales type II / III trap (Sales, 1993)

The pre-uplift history of the sedimentary basin is instrumental for preserving oil



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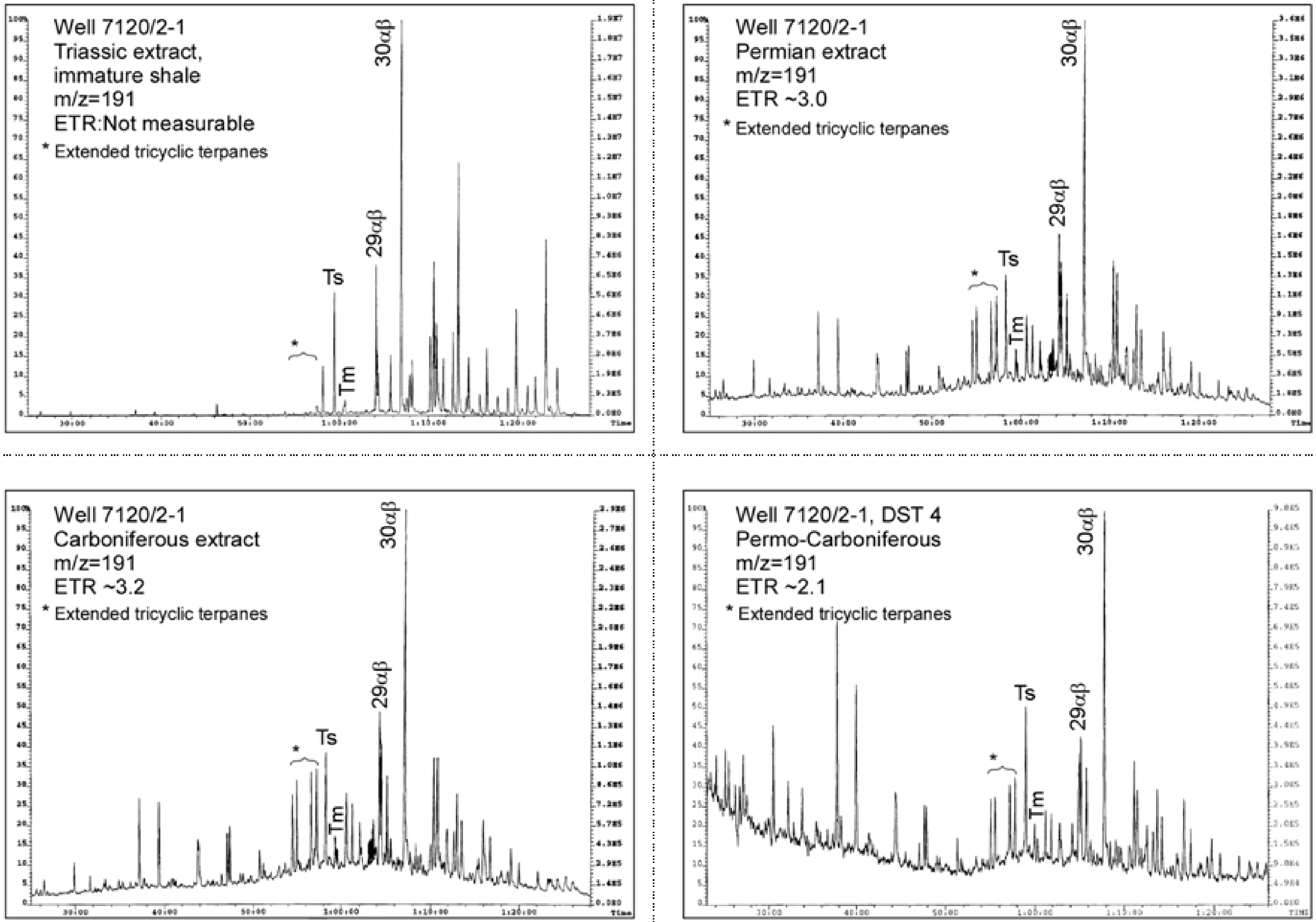
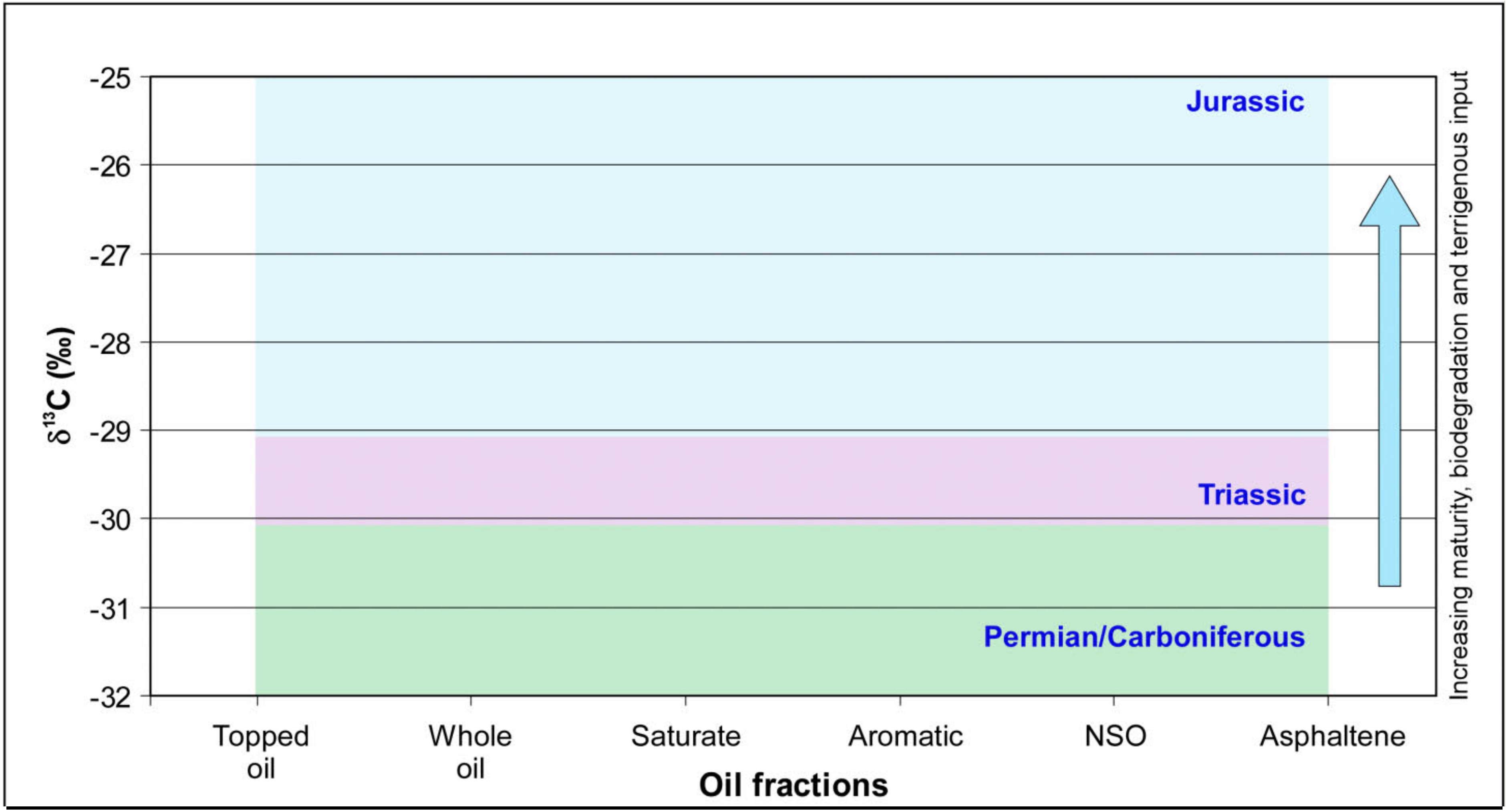

Well 7120/2-1
Triassic extract,
immature shale
m/z=191
ETR:Not measurable
* Extended tricyclic terpanes
30αβ
29αβ
Ts
Tm
*
Well 7120/2-1
Permian extract
m/z=191
ETR ~3.0
* Extended tricyclic terpanes
30αβ
29αβ
Ts
Tm
*
Well 7120/2-1
Carboniferous extract
m/z=191
ETR ~3.2
* Extended tricyclic terpanes
30αβ
29αβ
Ts
Tm
*
Well 7120/2-1, DST 4
Permo-Carboniferous
m/z=191
ETR ~2.1
* Extended tricyclic terpanes
30αβ
29αβ
Ts
Tm
*



Jurassic
Triassic
Permian/Carboniferous
-25
-26
-27
-28
-29
-30
-31
-32
δ13C (‰)
Topped oil
Whole oil
Saturate
Aromatic
NSO
Asphaltene
Oil fractions
Increasing maturity, biodegradation and terrigenous input

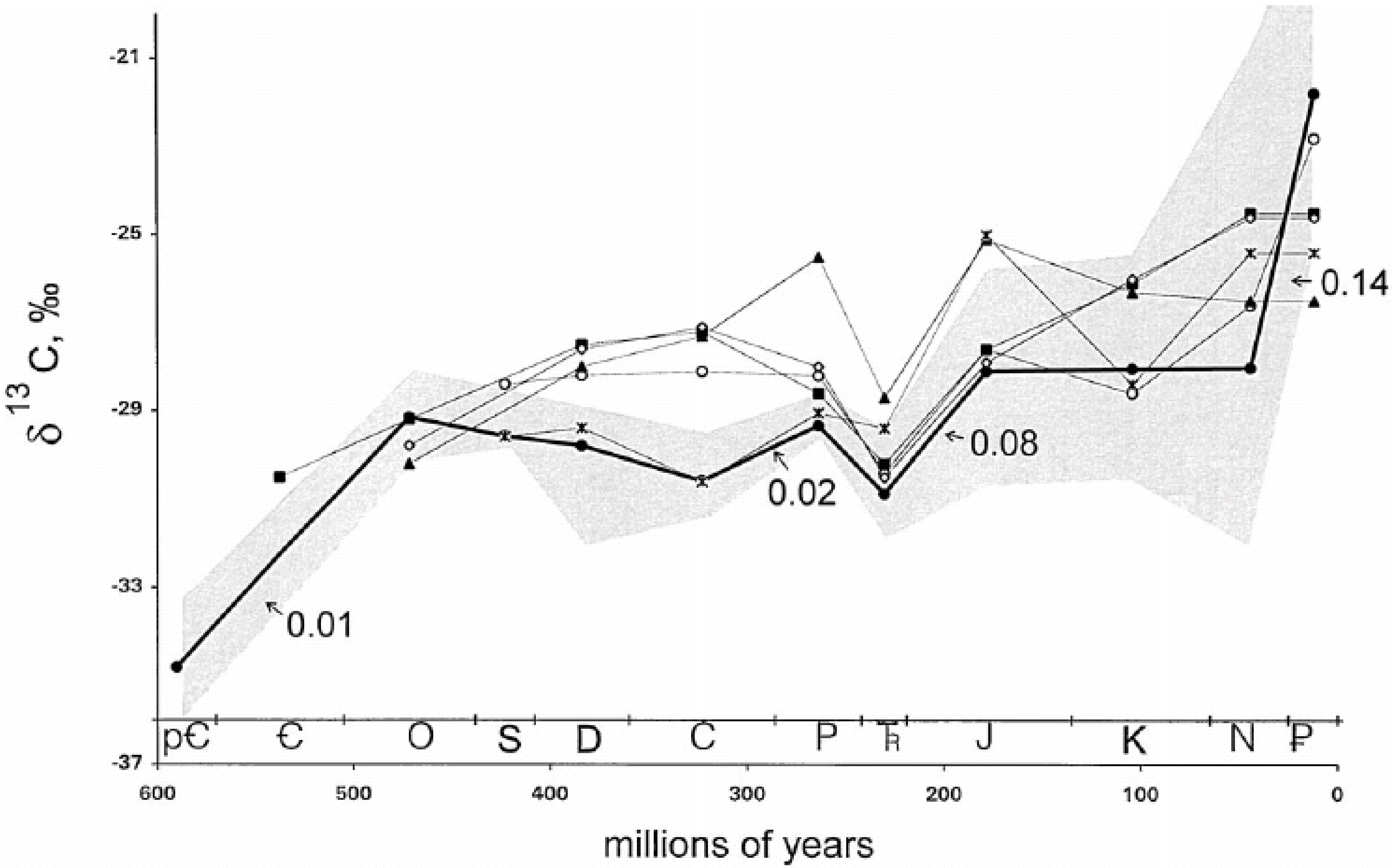
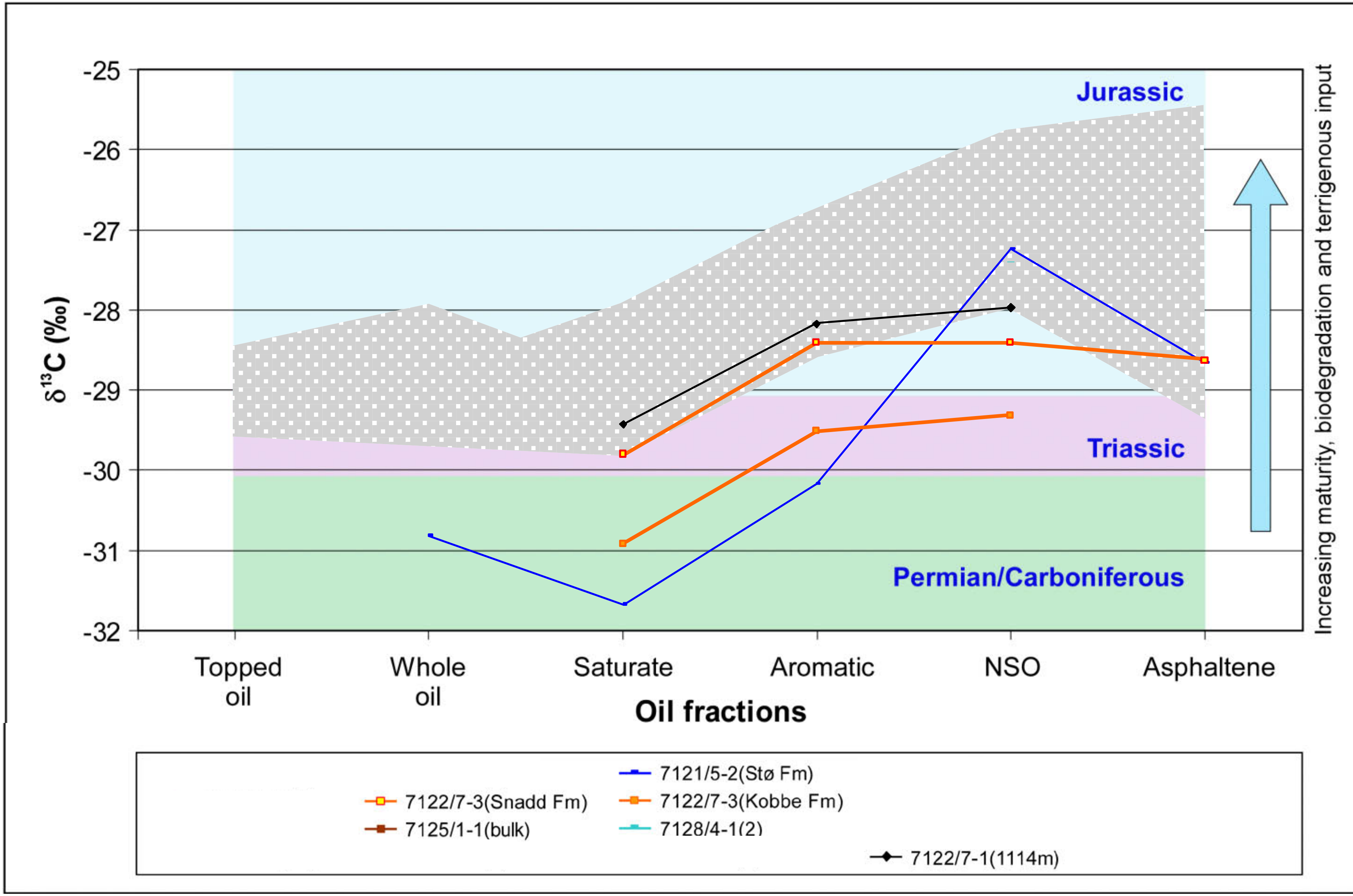
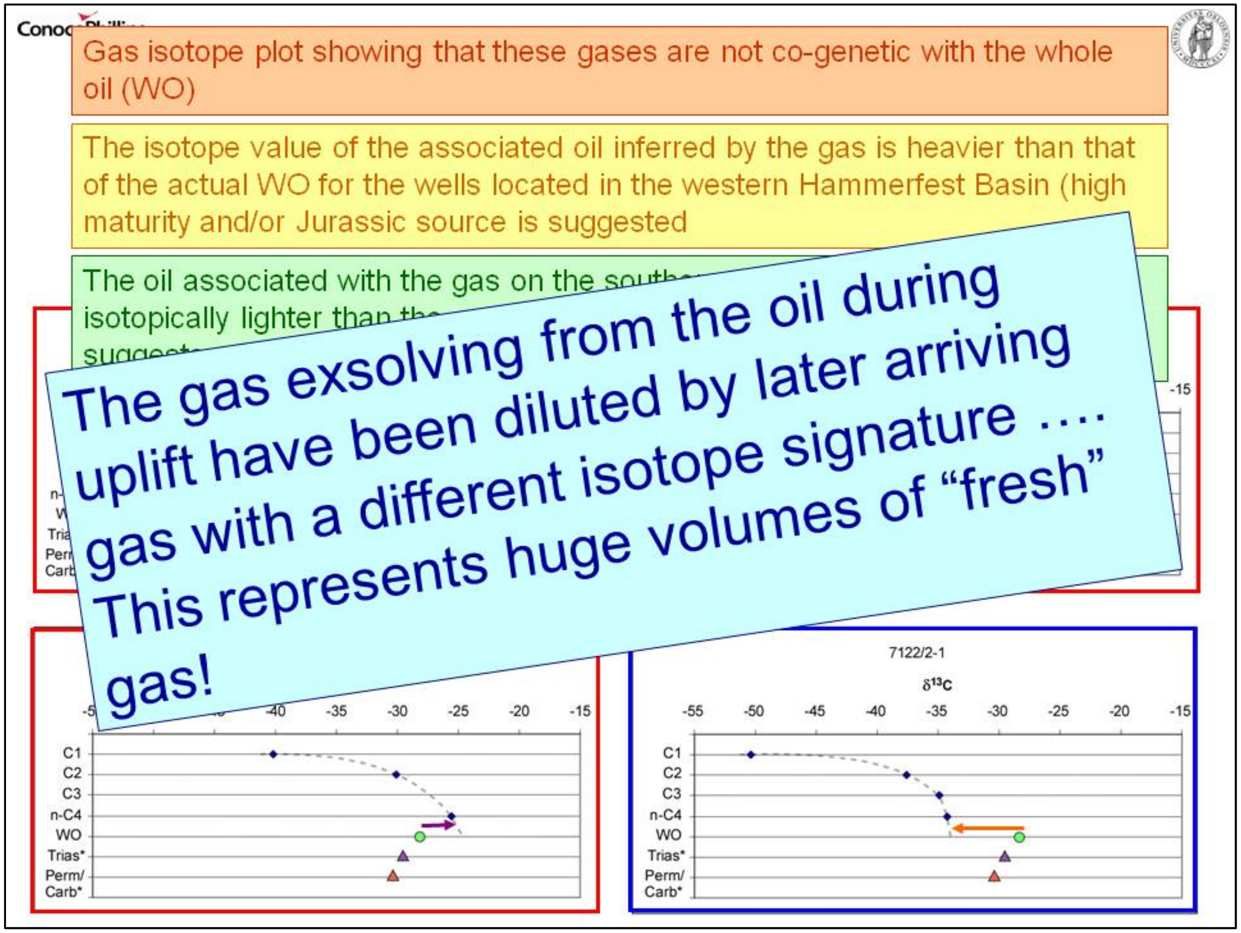


Fig. 1. Stable carbon isotope composition of crude oils vs. geologic age. (●) crude oil C_{15+} saturates (this study), (○) marine crude oils (Chung et al., 1992), (■) crude oils (Stahl, 1977), (×) crude oils (Grizzle et al., 1979), (▲) crude oils, European continent (◇) crude oils, American continent (Botneva et al., 1984). Numbers indicate the changes in ‰ per M.y. Shaded area indicates the δ^{13}C ranges of crude oil C_{15+} saturates (this study).



-25
-26
-27
-28
-29
-30
-31
-32
δ13C (‰)
Jurassic
Triassic
Permian/Carboniferous
Increasing maturity, biodegradation and terrigenous input
Topped oil
Whole oil
Saturate
Aromatic
NSO
Asphaltene
Oil fractions
7121/5-2(Stø Fm)
7122/7-3(Snadd Fm)
7122/7-3(Kobbe Fm)
7125/1-1(bulk)
7128/4-1(2)
7122/7-1(1114m)

Strong circumstantial evidence for live petroleum system



Notes by Presenter:

The gas fractions of oils are co-genetic (cf. Schoell, 1983) with the oil if the gaseous species from C1 to C4 and C5 asymptotically approach the isotope value of the whole oil (Chung et al., 1992). The isotope value of C4 should in this case be maximun 1- 2 per mill from the d13C of the saturate fraction. Most of the Barents Sea gases are co-genetic with their co-existing oils. There are, however, some exceptions, which are outlined in Figure 16.

This infers that the gases have another source than their co-existing oils. It could be argued that the heavier gas isotope values of the gas fractions in wells 7119/12-3, 7120/7-1 and 7120/8-1 are due to higher maturation of the source rock generating the gas and not necessarily reflecting a different source rock. The presence of non-co-genetic gas is, however, intriguing as pressure release during uplift, as previously discussed, would have resulted in formation of vast volumes of gas, which would have in turn completely overprinted any other gas signature. The only explanation for the presence of the non-co-genetic gases is that they have arrived after the event of uplift and pressure release (*i.e.* present day). It would take huge volumes of “fresh” gas to dilute/alter the isotope values of the original gas released due to pressure release. The consequence of this is important as it implies that there is presently a live petroleum system in the western Hammerfest Basin.

The gas isotopes of well 7122/2-1 (Fig. 16) show the opposite trend with the gases having lighter isotope values than the associated oil. This well located on the southeastern side of the Loppa High, thus suggests a live petroleum system in this area. The oil and gas discovery announced by StatoilHydro in well 7226/6-1 may belong to this petroleum system suggesting it to be working in the southeastern and eastern rim of the Loppa High.

There is a close isotopic similarity between n-C4 and the average Triassic and Permo-Carboniferous oil signatures in well 7120/2-2 (Fig. 17) where no isotope data for the co-existing whole oil exists. This well is located on the rim of the Loppa High, not very far from the 7120/1-2 well (Fig. 1) containing oil previously argued to stem from a Triassic source rock. The gas data, thus, consistently suggest a pre-Jurassic source for the oil of well 7120/2-2.

Conclusions

Traps with less well developed top seal stand the highest chance for retaining oil in uplifted areas …. allowing gas to escape, retaining oil

Uplift, erosion and pressure release is not necessarily devastating for oil accumulations….(deeply buried accumulations, undersaturated oil accumulations, oil accumulations which have undergone subsidence before uplift)

Several of the oils analysed show strong evidence of being mixtures of oils from different stratigraphic source intervals, which may suggest leakage from deeper yet undrilled accumulations

There is a strong indirect evidence for presence of a live gas petroleum system in some of the Barents Sea wells. Thus, the uplift has not resulted in all the petroleum systems becoming “frozen” at pre-uplift situation.

Suggested strategy to find oil

Drill shallow in basin periphery settings where the cap rock allows gas to bleed off.

Long distance migration will favor oil as more gas will be lost.

Drill deeper where oil stand a higher chance of surviving uplift.

We are grateful to ConocoPhillips for supporting publication of the article

…and to the University of Oslo for funding our presence here

Thank you for your attention!