Chalk exploration in the UK Central Graben

Gijs Fehmers, May 2013

Conclusions

1. The key elements in hydrocarbon exploration strategy are charge, trap, seal, and reservoir (sand) presence. In a chalk setting, presence of chalk is not the issue. Instead, it is the porosity of the chalk that is key.
2. The quality of chalk as a reservoir quickly decreases with burial. Without porosity preservation, chalk porosity falls below 20% at ~1.7 km burial. Here it effectively ceases to be reservoir as permeability drops well below 1 mD.
3. Chalk porosity can be preserved by overpressure and by early hydrocarbon charge.
4. Overpressures, and to a lesser extent early charge, have preserved chalk porosity on the Scandinavian side of the Central Graben. On the UK side, Paleogene sands have bled off overpressures and hydrocarbons from the chalk. That explains why on that side chalk porosity is not preserved and why the chalk is so much less prolific a reservoir.
5. Acoustic impedance from seismic is an excellent tool to image chalk porosity, as long as the chalk is pure. Attempts to predict chalk pore fluids from seismic have not been successful.

I.
Chalk in the UK Central Graben

1. Introduction

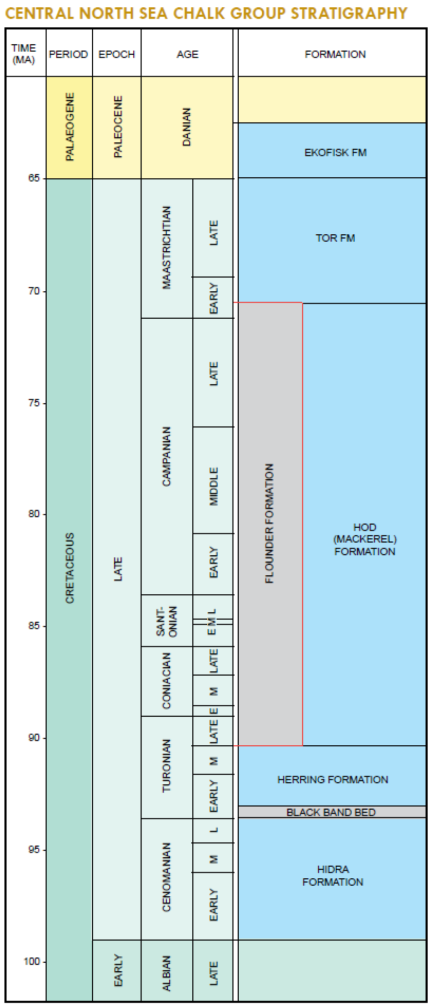


Figure 1.1. (from Canadian Discovery, 2011)

In the UK chalk, hydrocarbon reservoirs and shows in the chalk are confined to Quads 22-23 and 29-31. These quads form the area of interest (AOI) of the first and more general part of this report. The map in figure 1.2 shows the AOI in blue. The smaller red polygon delineates an area of 4200 km^2 covered by a PrSDM seismic cube that serves as the basis for the more focused second part of the study. For convenience, I'll refer to this cube and area as the HPHT area.

Of all play elements: charge, reservoir, and seal, this report is largely concerned with reservoir, or rather the quality of chalk as a reservoir rock. The reason will become clear.

Chalk was deposited from the Cenomanian (the Hidra formation) to the Danian (the Ekofisk Formation). This interval roughly coincides with the late Cretaceous. See stratigraphic diagram in figure 1.1.

In the Norwegian and Danish sectors of the Central North Sea (CNS), the chalk group forms a prolific reservoir rock with major oil accumulations. This is not the case in the UK. The question is why: why is the chalk west of the graben axis so much less prolific than east?

The UK offshore has no less chalk than Norway, nor are there fewer chalk fields (figure 1.2), the density of chalk fields may be lower in the UK, but the total number is not. Although the UK chalk fields contain far less hydrocarbons, the structural closures are not really smaller. The chalk is not thinner in the UK, nor is access to charge more problematic. Exploration has not been less intense. So why is the chalk not nearly as prolific? The answer is the reservoir quality: in Norway and Denmark, there's simply more and thicker high porosity chalk.

But why is reservoir quality so different? The UK chalk is on average not deeper or shallower, nor is the depositional environment any different, nor is the degree of reworking, nor is the clay content any higher (at least not in the main reservoir layer, the Tor).

It is generally thought that the main reason for the difference in porosity can be found in the overburden. Sand and silt in the Paleocene of the UK bled off overpressures and early hydrocarbons from the chalk, and these are essential for porosity preservation in the chalk. These sands are absent on the Scandinavian side.

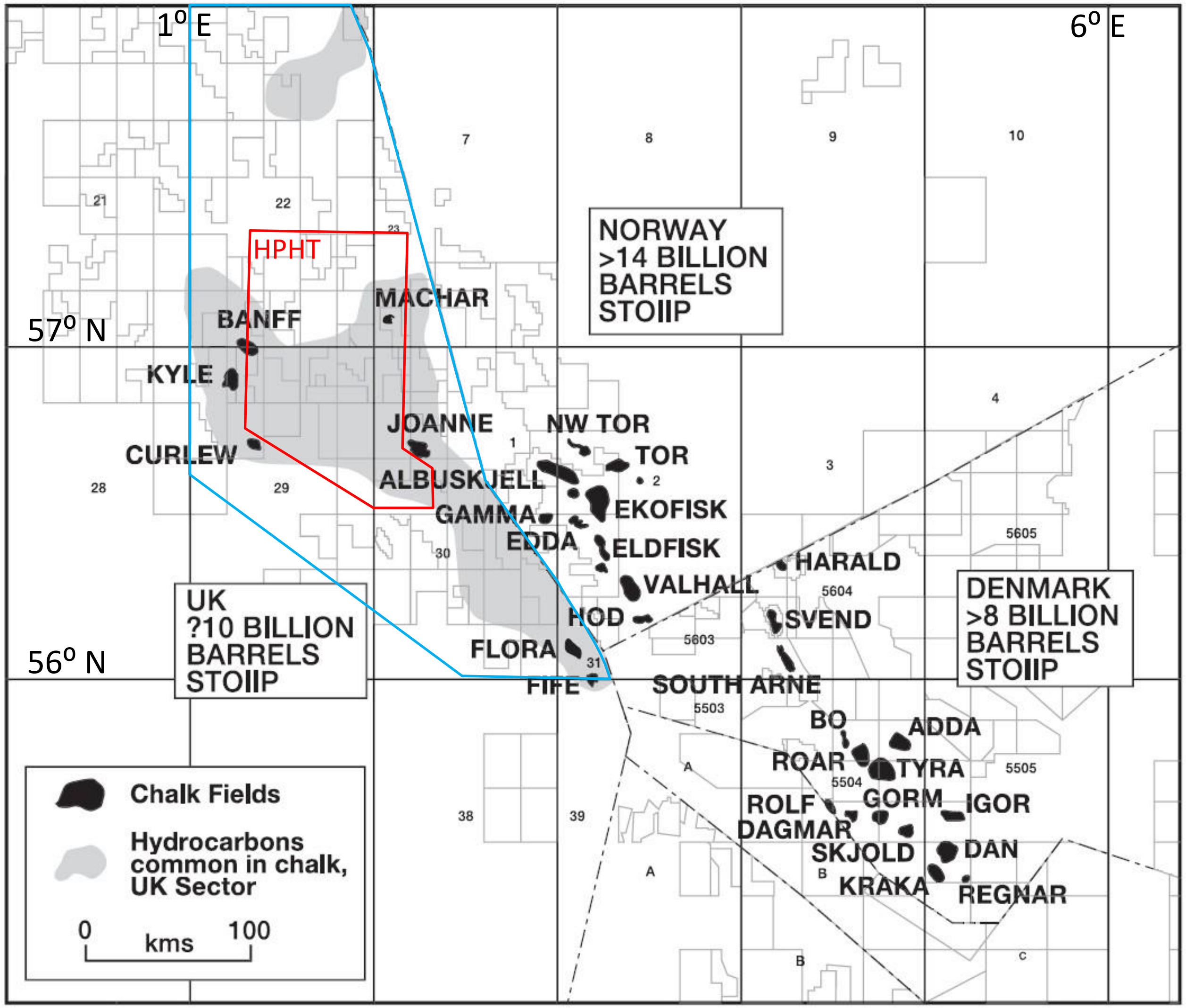
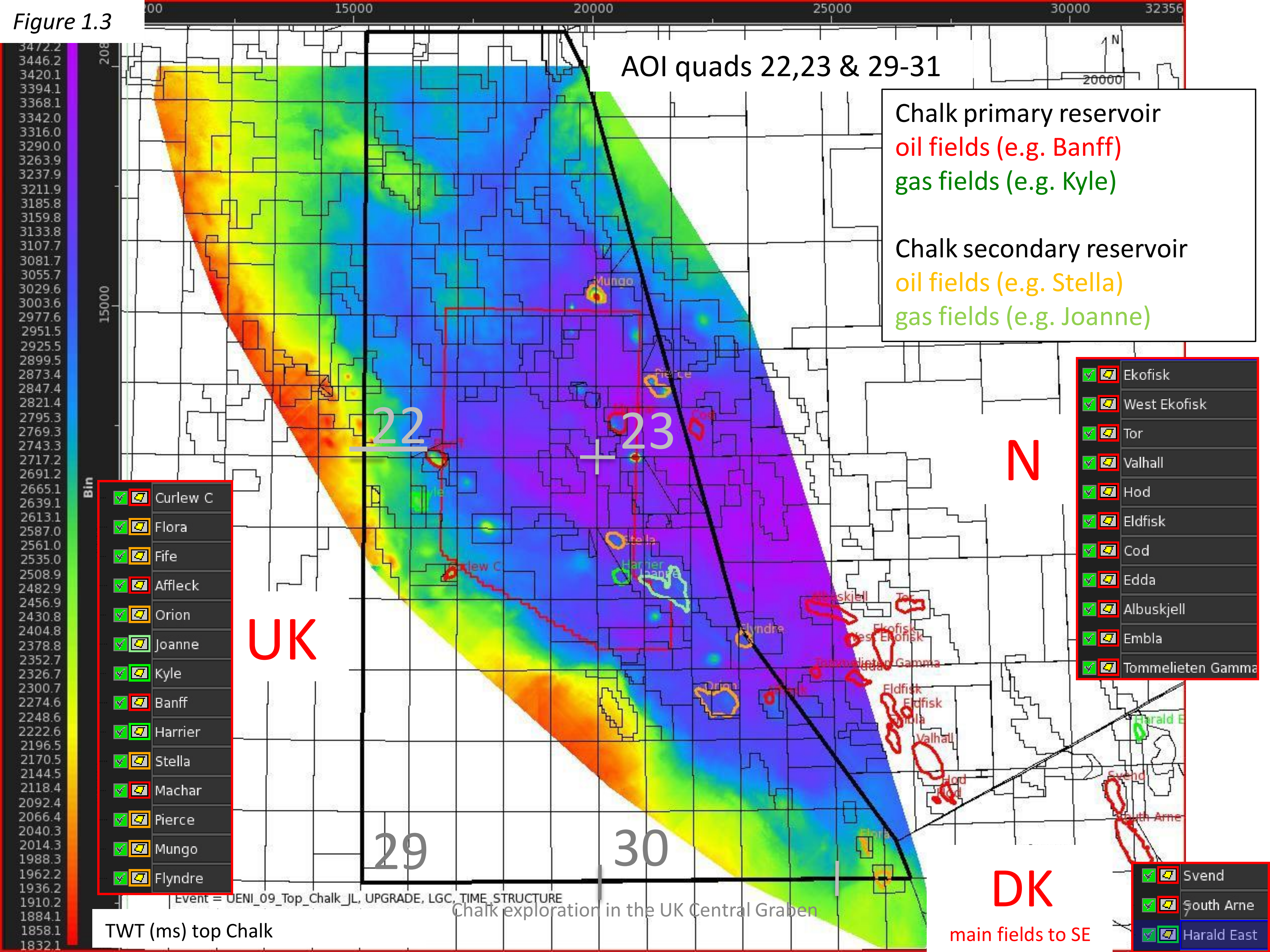


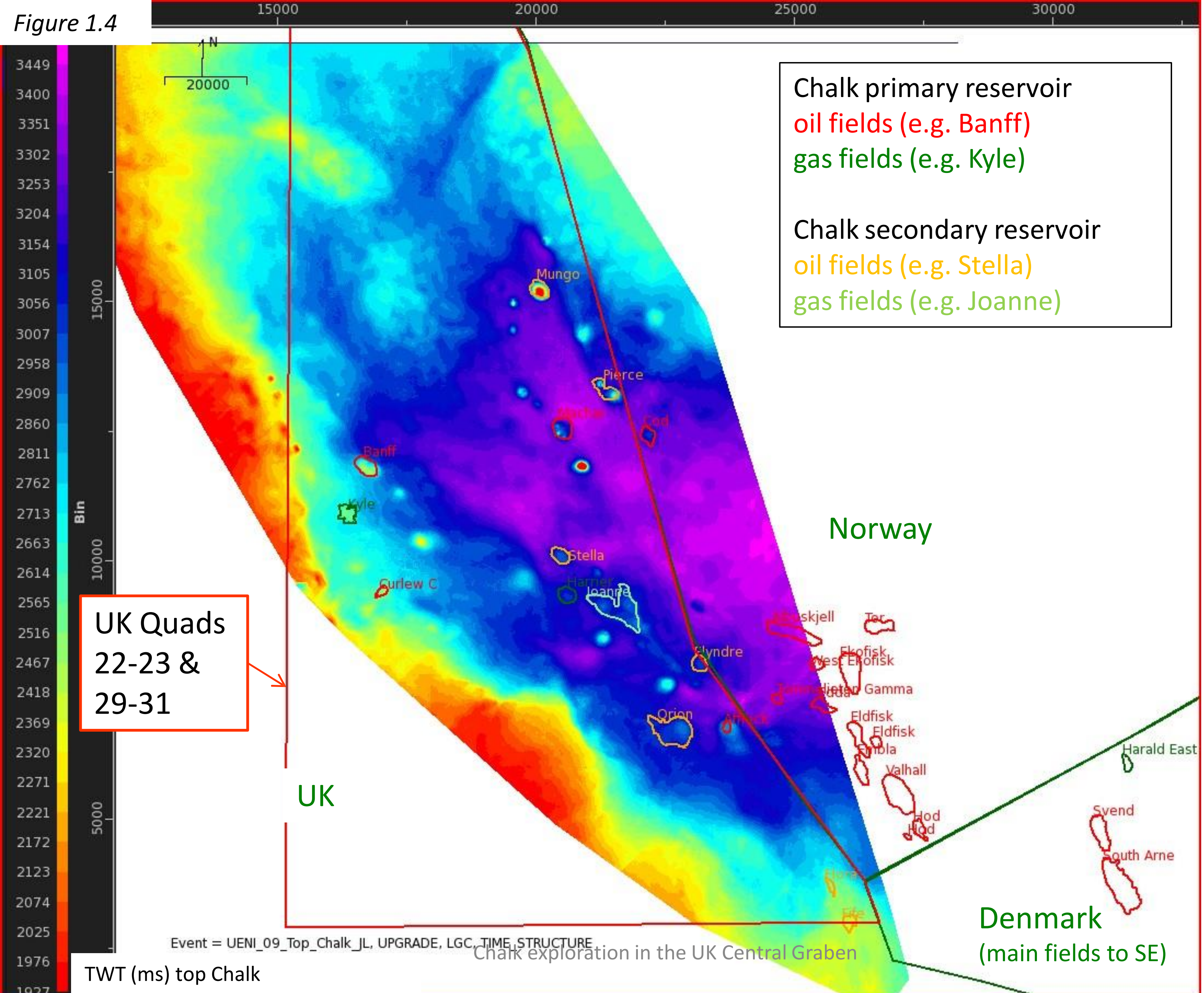
Figure 1.2. Chalk fields in the UK, Danish and Norwegian sectors of the Central Graben. Also shown is the area within the UK Central Graben within which hydrocarbon shows are commonly encountered in the chalk. The numbers are estimates of in place volumes (oil and gas equivalent) in each sector. From Megson & Hardman 2001.

Figure 1.3



AOI quads 22,23 & 29-31
Chalk primary reservoir
oil fields (e.g. Banff)
gas fields (e.g. Kyle)
Chalk secondary reservoir
oil fields (e.g. Stella)
gas fields (e.g. Joanne)
22
23
29
30
UK
N
DK
main fields to SE
TWT (ms) top Chalk
Event = UENI_09_Top_Chalk_JL, UPGRADE, LGC, TIME_STRUCTURE
Chalk exploration in the UK Central Graben
Curlew C
Flora
Fife
Affleck
Orion
Joanne
Kyle
Banff
Harrier
Stella
Machar
Pierce
Mungo
Flyndre
Ekofisk
West Ekofisk
Tor
Valhall
Hod
Eldfisk
Cod
Edda
Albuskjell
Embla
Tommelieten Gamma
Svend
South Arne
Harald East
15000
20000
25000
30000
32356

Figure 1.4


15000
20000
25000
30000
N
20000
Chalk primary reservoir
oil fields (e.g. Banff)
gas fields (e.g. Kyle)
Chalk secondary reservoir
oil fields (e.g. Stella)
gas fields (e.g. Joanne)
3449
3400
3351
3302
3253
3204
3154
3105
3056
3007
2958
2909
2860
2811
2762
2713
2663
2614
2565
2516
2467
2418
2369
2320
2271
2221
2172
2123
2074
2025
1976
1927
Bin
15000
10000
5000
Mungo
Pierce
Cod
Banff
Kyle
Stella
Curlew C
Joanne
Norway
UK Quads 22-23 & 29-31
Skjell
Tor
Ekofisk
Embla
Flyndre
Gamma
Eldfisk
Valhall
Orion
Hod
Harald East
Svend
South Arne
UK
Denmark
(main fields to SE)
Event = UENI_09_Top_Chalk_JL, UPGRADE, LGC, TIME, STRUCTURE
TWT (ms) top Chalk

2. Chalk reservoir

2.1 Chalk reservoir stratigraphy

Chalk is generally purest in the Tor and Ekofisk (figure 1.1), although the Ekofisk often sees some contamination with clays and sometimes silt, especially when there's a gradual transition from Tertiary clays and muds into the chalk. The Hod, Herring and Hidra have increasingly more clays and higher Gamma Ray (GR) readings. The Plenus Marl ('black band bed') between the Herring and Hidra is a regional non-chalk interval within the late Cretaceous, with high GR.

Tor, and to a lesser degree the Ekofisk, are the reservoir intervals. The Tor is generally better than the Ekofisk. One reason is the above-mentioned clay contamination in the Ekofisk. The other is that the coccoliths in the Cretaceous Maastrichtian were larger than in the Paleocene, and larger particles make for larger pore diameter and better permeability for a given porosity (next section).

In the Hod, Herring and Hidra, porosity, and more importantly, permeability are too low to be viable reservoirs. Having said this, a few fields fields in Norway and Denmark (Adda) do produce from the Hod, but it's always secondary. Even the Hod field (Norway) gets most of the productivity from the Tor, with the Hod contributing marginally. Porosity and permeability in the Herring and Hidra are worse still. Having said this, a Danish prospect (called Ve) in the Hidra Formation is on the sequence for 2013 (well B0-4X).

2.2 Chalk porosity

Pure chalk consists of coccoliths. These are calcareous ($CaCO_3$) disks that cover unicellular algae called coccolithophorids. Today's coccoliths are very small, with a size of the order of 2 micrometer. These pelagic algae can give rise to algal blooms (figure 2.1). These algae had their heyday during the warm climate of the late Cretaceous, when they were both more prevalent and larger (about 10 times the size) than today. Upon their deaths, coccolithophorids sink to the sea floor, probably in faecal pellets, where they disintegrate into coccoliths and parts thereof (figure 2.2). At the seafloor, these form a sediment of high porosity (60-80%). This porosity quickly decreases with burial.

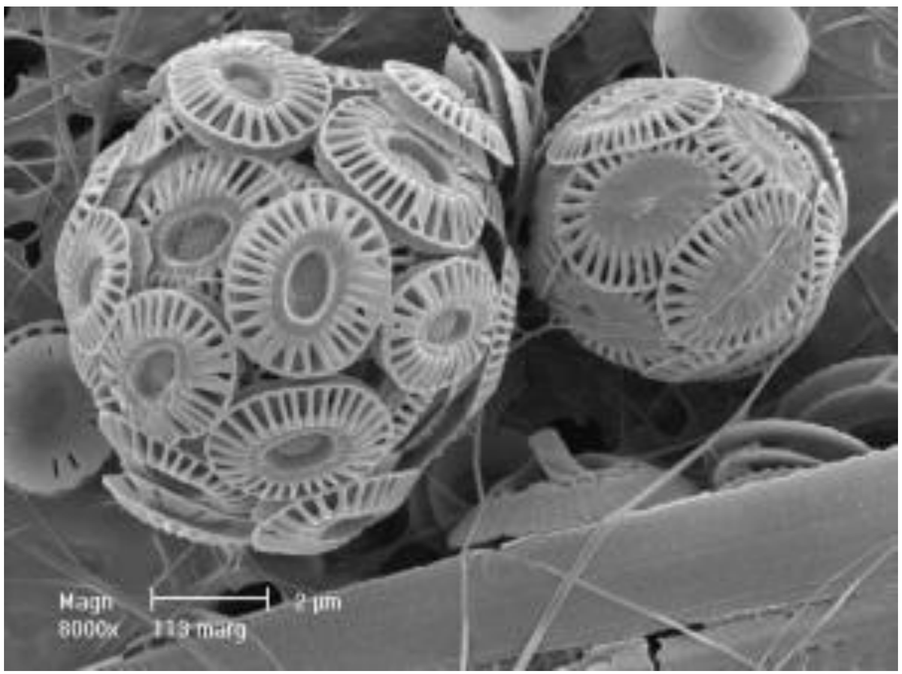


Figure 2.1 Picture of modern coccolithophores and an algal bloom off the southwestern coast of England.

Figure 2.2 shows SEM images of Tor chalk, and arguably the most important part of the figure is the scale bar. The individual carbonate ‘grains’ are exceedingly small, almost a factor 1000 smaller than sand grains. The pore diameter is similarly small, which explains why chalk permeability is 100-1000 times lower than that of sandstone with equal porosity. This is shown in the graphs of figure 2.3: a piece of Tor chalk with 25% porosity, has a permeability of only ~1mD, decreasing to 0.3mD for a piece of Ekofisk the same porosity (the Ekofisk has smaller coccoliths than the Tor and hence smaller pore throats).

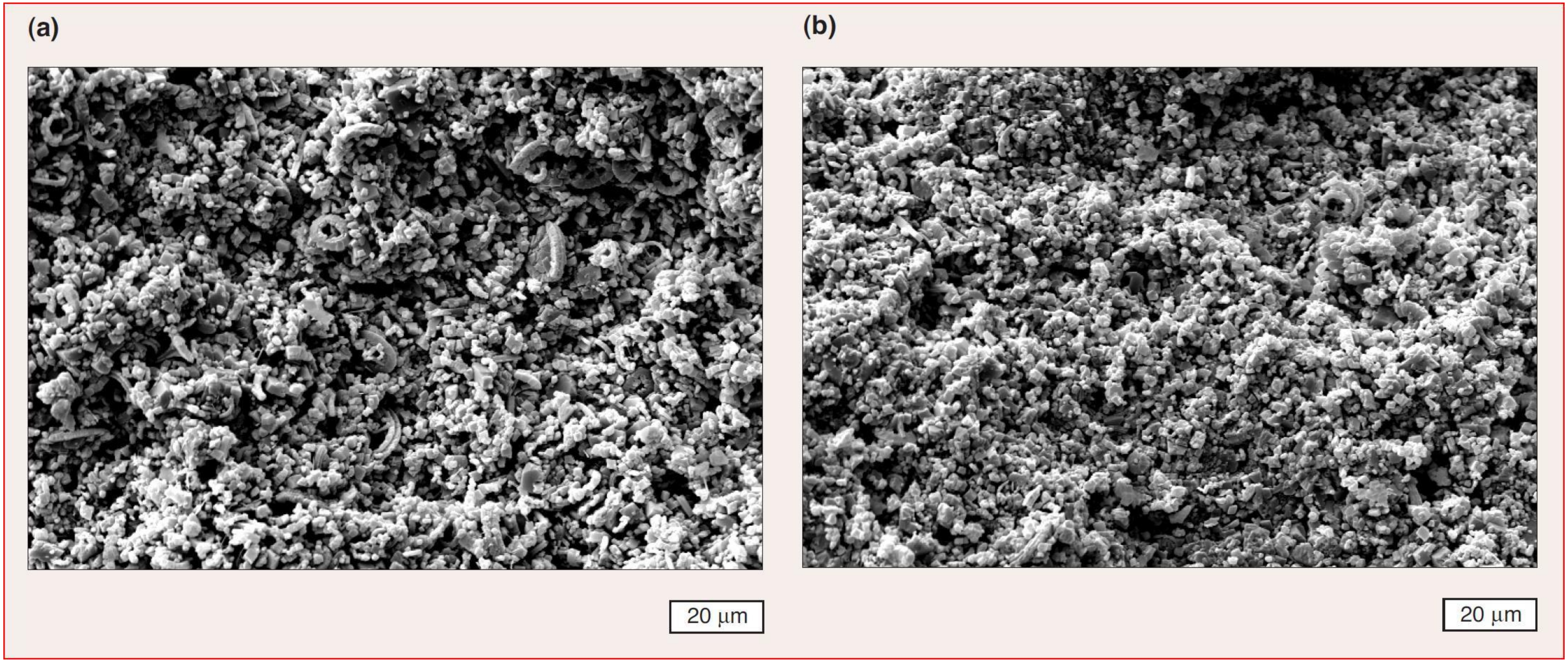


Figure 2.2 Millennium atlas: SEM photographs of chalk (Tor) from the Dan field, (a) Poorly cemented Tor with a porosity of 38.5% showing well preserved coccoliths (b) Well cemented Tor with a porosity of 27.5% showing recrystallised and calcite overgrown coccoliths

It’s obvious that in chalk, porosity is paramount: porosity determines permeability, and in its turn, permeability determines capillary entry pressure and hence saturation. In other words, when chalk porosity is low (<15%), hydrocarbons cannot even enter the rock. Of course, permeability has a big impact on recovery, too. It’s safe to say that 20% is a reasonable porosity cut-off for chalk reservoirs.

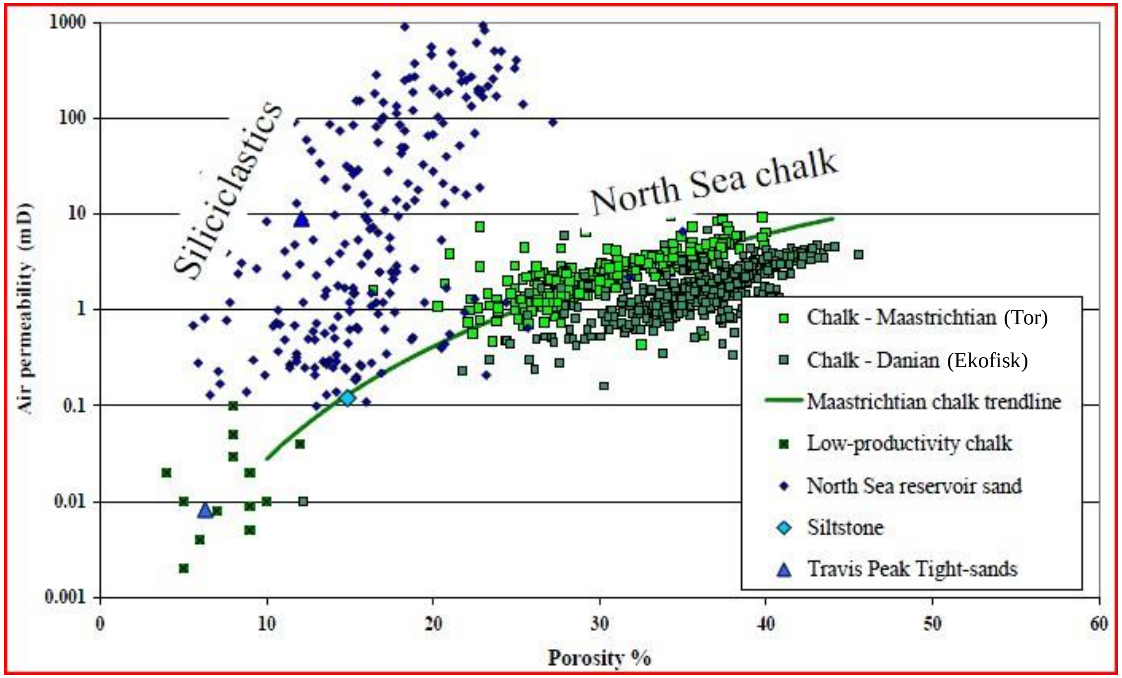


Figure 2.3 Permeability vs porosity (from Frykman 2002)

2.3 Chalk porosity preservation

Figure 2.4 shows schematically how chalk porosity decreases with burial. Without porosity preservation, chalk porosity falls below 20% at ~1.7 km burial, where it effectively ceases to be reservoir. With porosity preservation, fields can have a peak porosity in excess of 45% at a depth of 2 km (Tyra) or deeper (3.3 km, Ekofisk).

The figure also shows that there are 3 mechanisms of porosity preservation, in order of increasing importance: **reworking, early hydrocarbon entry,** and **overpressure**.

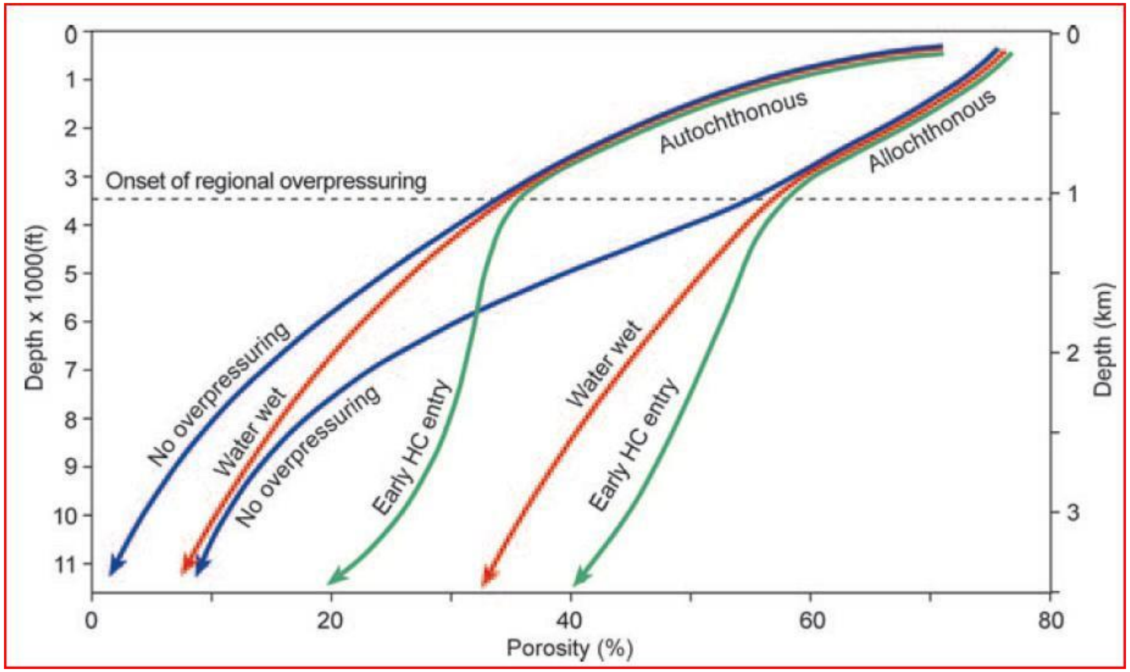


Figure 2.4 Chalk porosity preservation, adapted by Megson & Tygesen (2005) from Brasher and Vagle (1996)

Reworking is assumed to increase the porosity, figure 2.4 puts reworked chalk (allochthonous) at higher porosity than pelagic chalk (autochthonous) and this effect persists throughout the whole burial history.

This is controversial, as reworking is also known to reduce permeability. Also, the Tyra field (pelagic chalk, 2km depth) has porosity of up to 48 %. According to the graph this should not happen for chalk that has not been reworked. Another issue is the evidence for the statement that a particular chalk is reworked. For example, it's often argued that the crest of the Dan field consists of reworked chalk. Core data show no real evidence for this, other than high porosity, which of course leads to a circular argument. And there is another problem: how would reworked chalk be deposited on the crest of a structure? Most, though indeed not all, chalk fields have the highest porosity at what used to be the crest of the structure throughout the structural evolution.

Early charge reduces pressure dissolution and cementation, as calcite does not dissolve in hydrocarbons. In exploration, early charge may be conjectured from palaeo-closures, which can be identified from the structural evolution. This is a useful tool in chalk exploration. Megson and Tygesen (2005) and Megson and Hardman (2001) argue that the chalk in the Norwegian and Danish sectors is overall thinner than in the UK. This facilitated (early) migration of hydrocarbons through the low permeability lower chalk into the upper chalk (Tor and Ekofisk) thereby facilitating porosity preservation. Early chalk charge of course requires the Paleogene clastics to be sealing. Palaeocene sands (such as the Maureen sands) on the UK side of the graben would bleed off hydrocarbons.

Overpressure is the situation where the pore fluid carries (part of) the overburden weight. This reduces the vertical effective stress of the matrix, which means that the stress (pressure) on grain-to-grain contacts is reduced. Overpressure thus reduces compaction (mechanical failure of the matrix), and pressure dissolution.

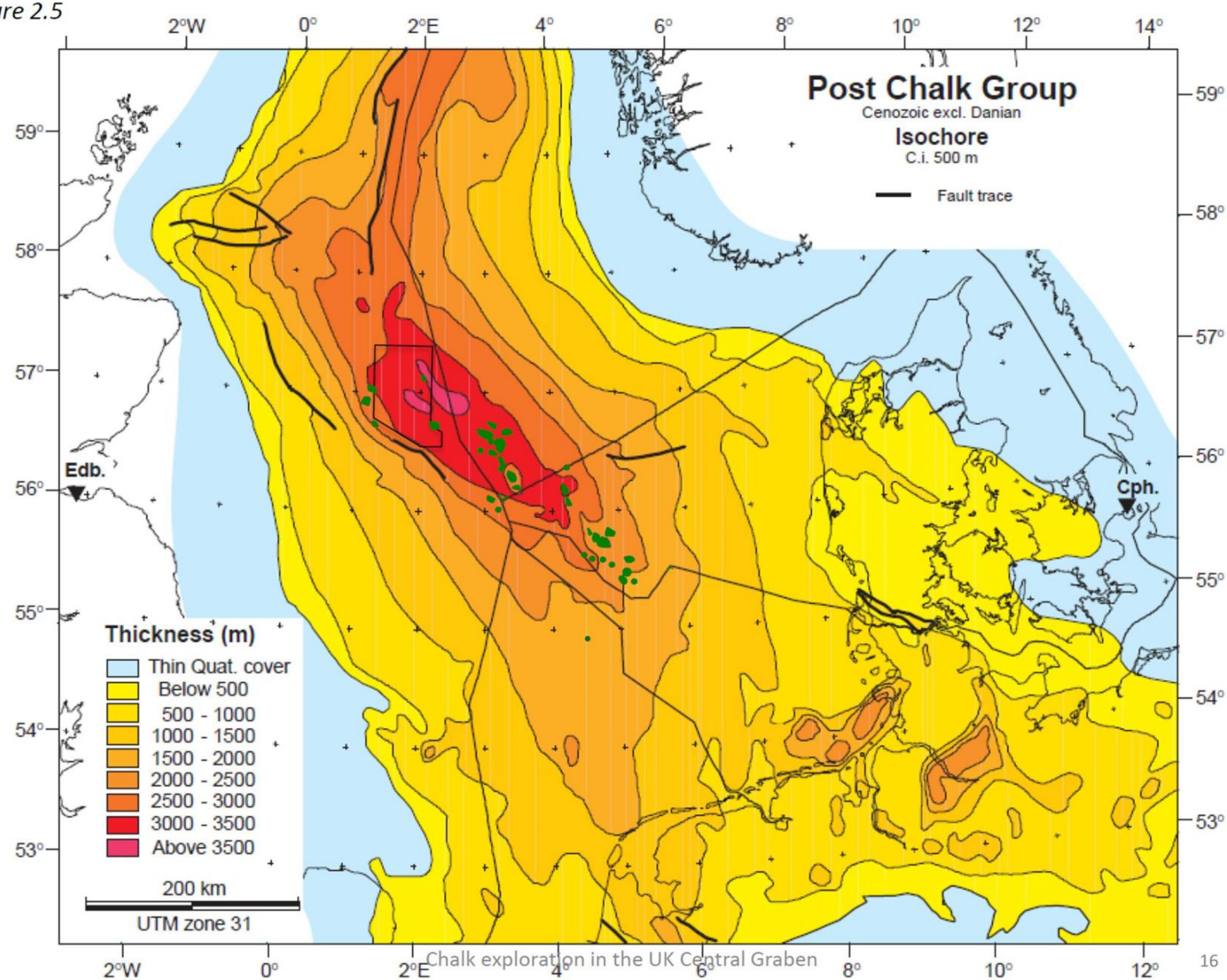
Chalk and Tertiary overpressures in the North Sea have been studied by Japsen (1998, 1999). I have reproduced his maps on the following pages, and overlain them with the chalk fields. The maps show thickness of overburden (figure 2.5), chalk group thickness (figure 2.6), chalk overpressure and chalk 'burial anomaly' (figure 2.7). The burial anomaly is defined as the difference between the actual depth of a piece of rock and the depth the rock should be at to explain its measured sonic velocity. A positive burial anomaly –sonic velocity too low for its depth - can be caused by overpressure, a negative one by inversion.

Japsen divides the post chalk sequence into an upper and lower post chalk group. These groups are separated by the Mid Miocene Unconformity. The lower post chalk is also known as overpressured (or 'sticky') shales. Overpressures in these shales and chalk were caused by rapid and massive deposition from the mid Miocene onwards. And indeed, the maps (figure 2.7) show that significant overpressure (≥10 MPa) only occurs where the depth to the Mid Miocene Unconformity exceeds 1250 m. Moreover, these overpressures are barely present where there's sand above the chalk in the Maureen Formation. The maps of figure 2.7 outline the Maureen sands by a hatched line (). This is consistent with the idea that sands bleed off the overpressure. In other words, chalk overpressure is caused by quick and substantial burial in the absence of sands bleeding off the overpressure.

It's obvious that chalk fields only occur where 1. the graben is deep enough for maturity in the upper Jurassic, and 2. where overpressures (≥10 MPa) counteract the adverse effect of burial on porosity. Ideally, I should combine maps of (1) Kimmeridge source rock maturity and (2) effective chalk burial depth (= chalk depth minus burial anomaly).

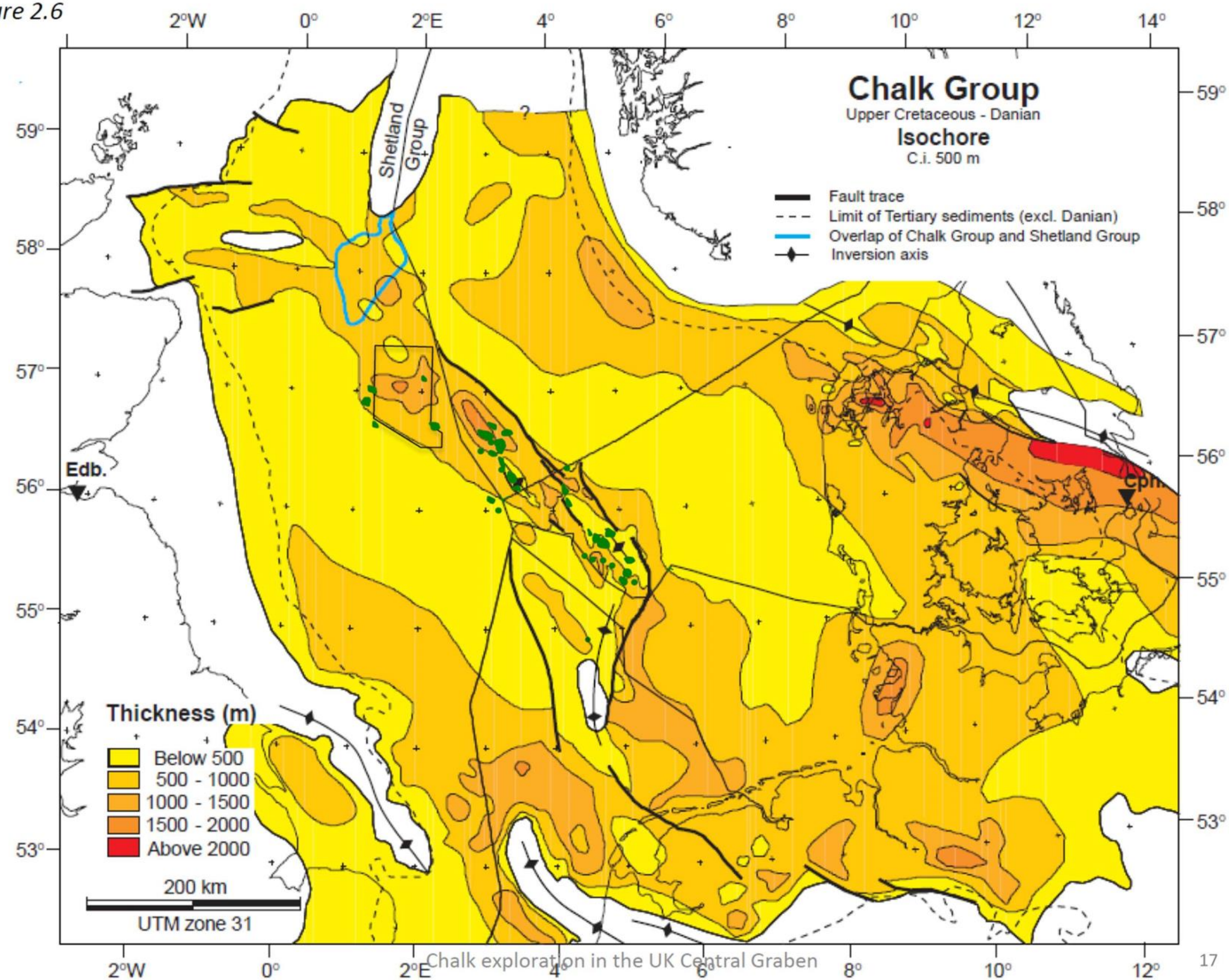
In **conclusion**, the Paleogene sands on the UK side of the Central Graben axis prevented the containment of both early hydrocarbons and overpressure in the chalk, while these are needed for porosity preservation. These sands are absent on the Scandinavian side, which explains why the chalk is so much more prolific there.

Figure 2.5



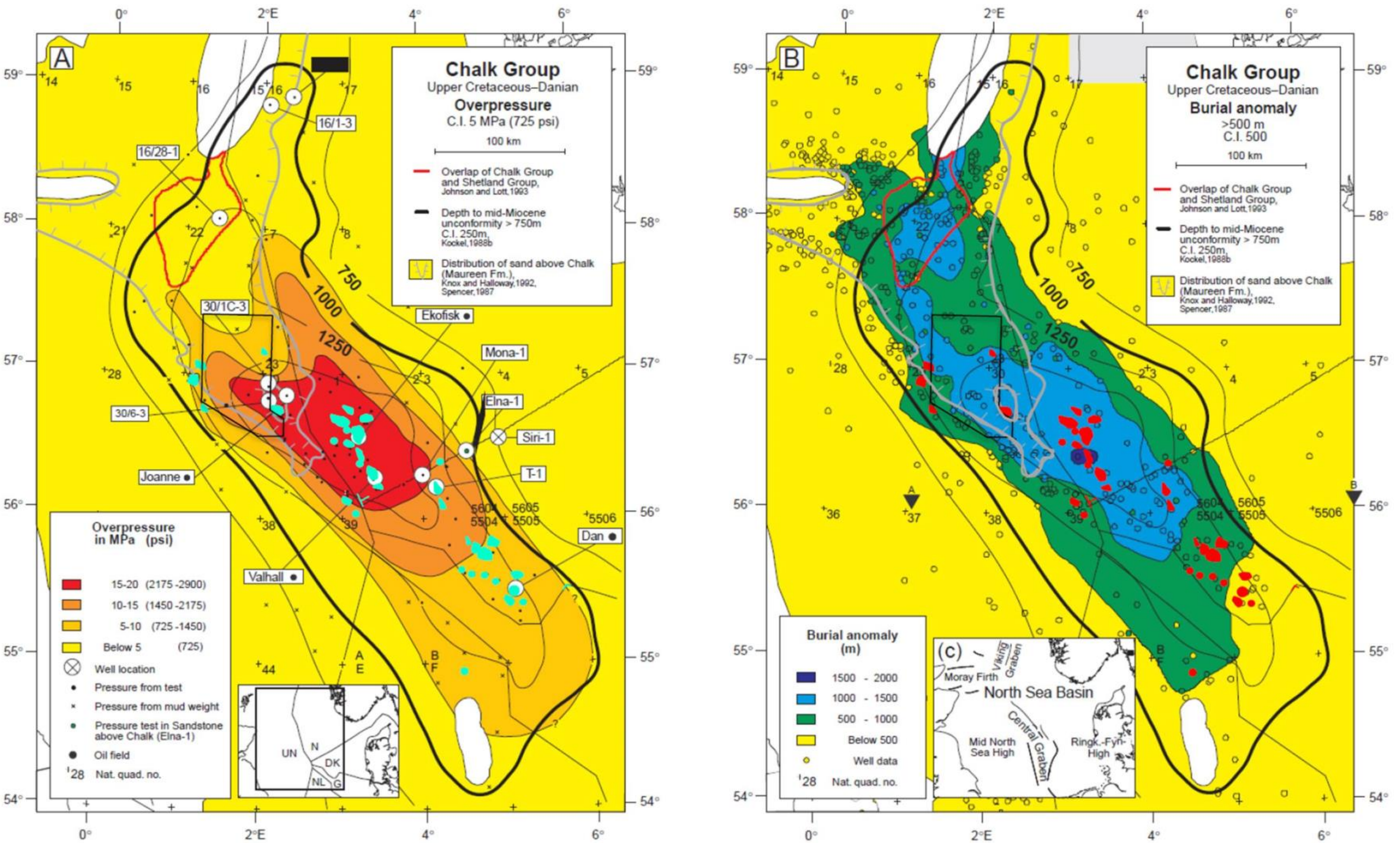
Post Chalk Group
Cenozoic excl. Danian
Isochore
C.i. 500 m
Fault trace
Thickness (m)
Thin Quat. cover
Below 500
500 - 1000
1000 - 1500
1500 - 2000
2000 - 2500
2500 - 3000
3000 - 3500
Above 3500
200 km
UTM zone 31
Edb.
Cph.
2°W
0°
2°E
4°
6°
8°
10°
12°
14°
59°
58°
57°
56°
55°
54°
53°

Figure 2.6



Chalk Group
Upper Cretaceous - Danian
Isochore
C.i. 500 m
Fault trace
Limit of Tertiary sediments (excl. Danian)
Overlap of Chalk Group and Shetland Group
Inversion axis
Shetland Group
Thickness (m)
Below 500
500 - 1000
1000 - 1500
1500 - 2000
Above 2000
200 km
UTM zone 31
Edb.
2°W
0°
2°E
4°
6°
8°
10°
12°
14°
59°
58°
57°
56°
55°
54°
53°

Figure 2.7



Corresponding areas of (A) overpressured Chalk outlined from pressure measurements and from (B) Chalk burial (=velocity) anomalies coincident with the late Cenozoic depocenter. (C) Late Cretaceous–Cenozoic structural elements. The overpressured zone corresponds to maximum thickness of the upper Post Chalk Group (mid Miocene-today), whereas Paleocene sands overlying the Chalk to the northwest (i.e. the UK side) cause bleed-off of overpressure. South of the Viking Graben, shaly Chalk causes positive velocity anomalies even where the Chalk is normally compacted. (From Japsen 1998). Main fields overlain in contrasting colours: pale blue (A) and red (B).

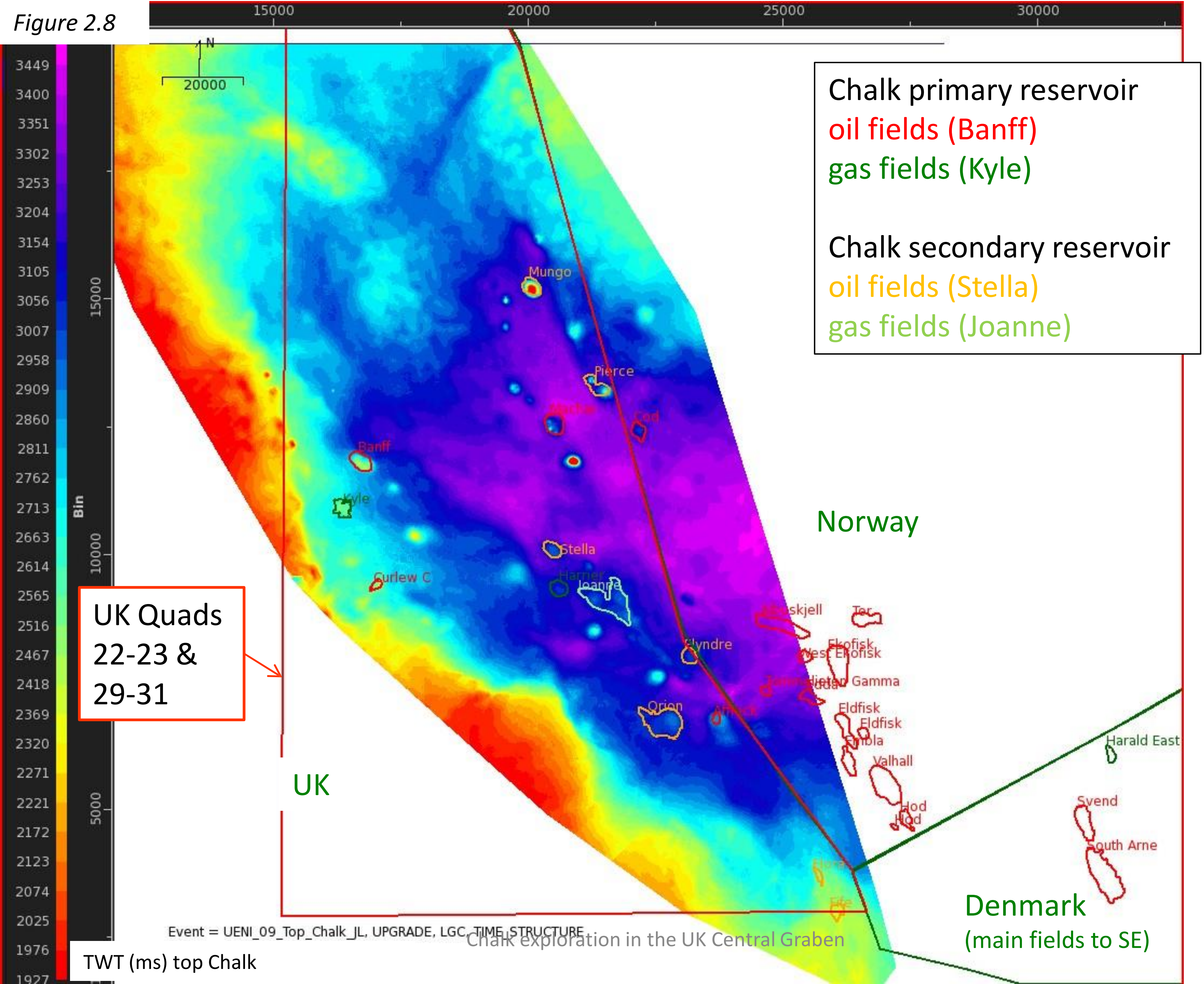
2.4 Maureen mass flows

The maps in figures 2.9-2.10 show the seismic expression of Maureen mass flows in the UK Central Graben. One map shows the top Chalk to top Sele isochron. Although the effect is quite subtle, this interval is a bit thicker where the mass flows occurred. This is thought to be the result of differential compaction.   The other map shows RMS seismic amplitudes in the lower third of the interval between top chalk and top Sele. The mass flows are more easily identifiable on this map.

2.5 Fracture porosity

So far we have discussed matrix (primary) porosity. But of course, there's also fracture porosity and the associated permeability. Examples of fractured chalk reservoirs are Machar (UK) and Skjold (DK), both situated on top of a salt cored anticline. These fractures greatly enhance (effective) permeability and productivity, but they do little to increase porosity nor to decrease capillary entry pressure (and hence increase saturation). Most of the hydrocarbons will have to come from the matrix, and chalk (matrix) porosity remains paramount.

Figure 2.8



Chalk primary reservoir
oil fields (Banff)
gas fields (Kyle)
Chalk secondary reservoir
oil fields (Stella)
gas fields (Joanne)
UK Quads 22-23 & 29-31
Norway
UK
Denmark
(main fields to SE)
TWT (ms) top Chalk
Event = UENI_09_Top_Chalk_JL, UPGRADE, LGC, TIME STRUCTURE
Bin
N
20000
15000
20000
25000
30000
3449
3400
3351
3302
3253
3204
3154
3105
3056
3007
2958
2909
2860
2811
2762
2713
2663
2614
2565
2516
2467
2418
2369
2320
2271
2221
2172
2123
2074
2025
1976
Mungo
Pierce
Cod
Banff
Kyle
Stella
Curlew C
Joanne
Tor
Glyndre
Gamma
Eldfisk
Valhall
Hod
Orion
Harald East
Svend
South Arne

Figure 2.9

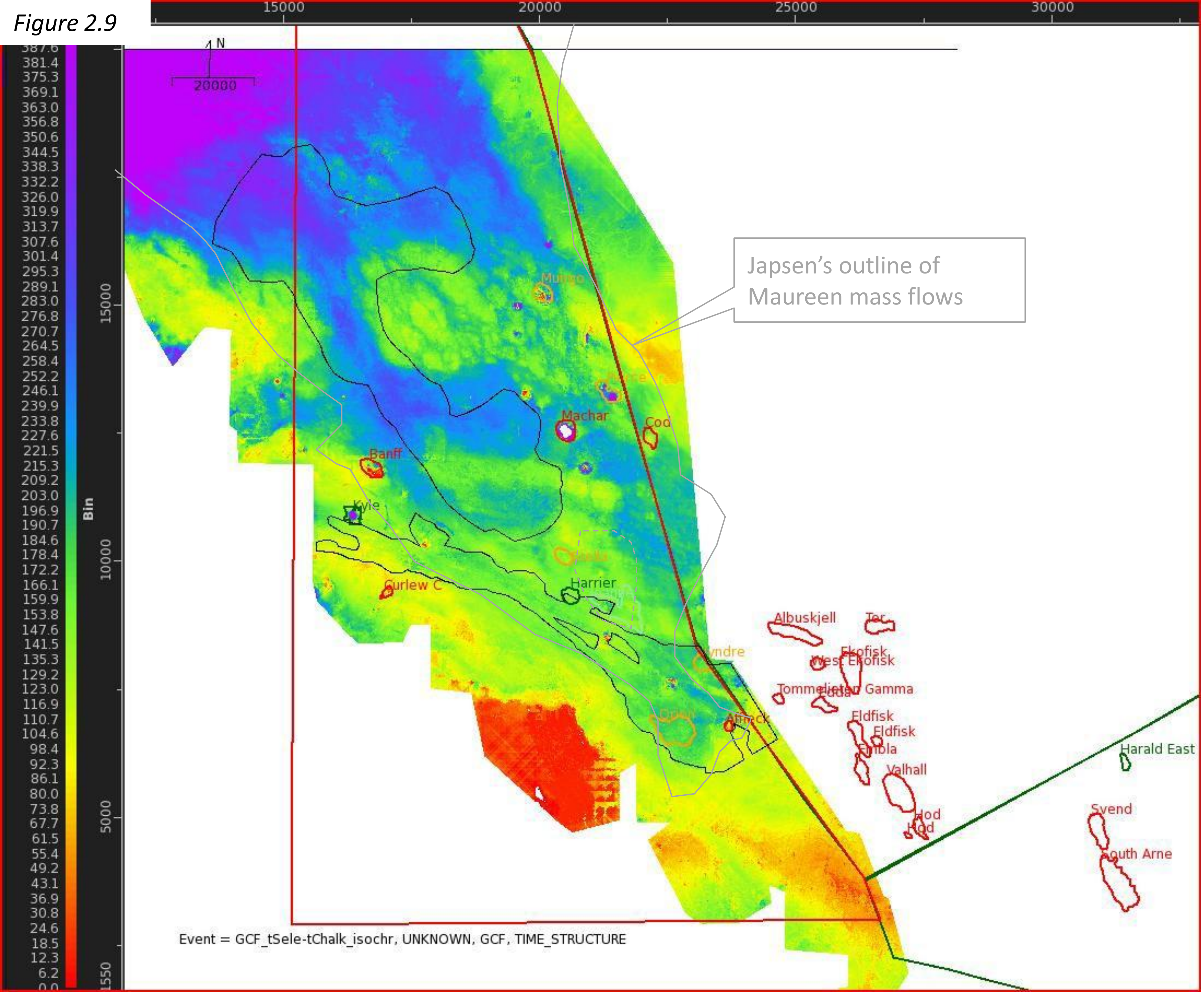
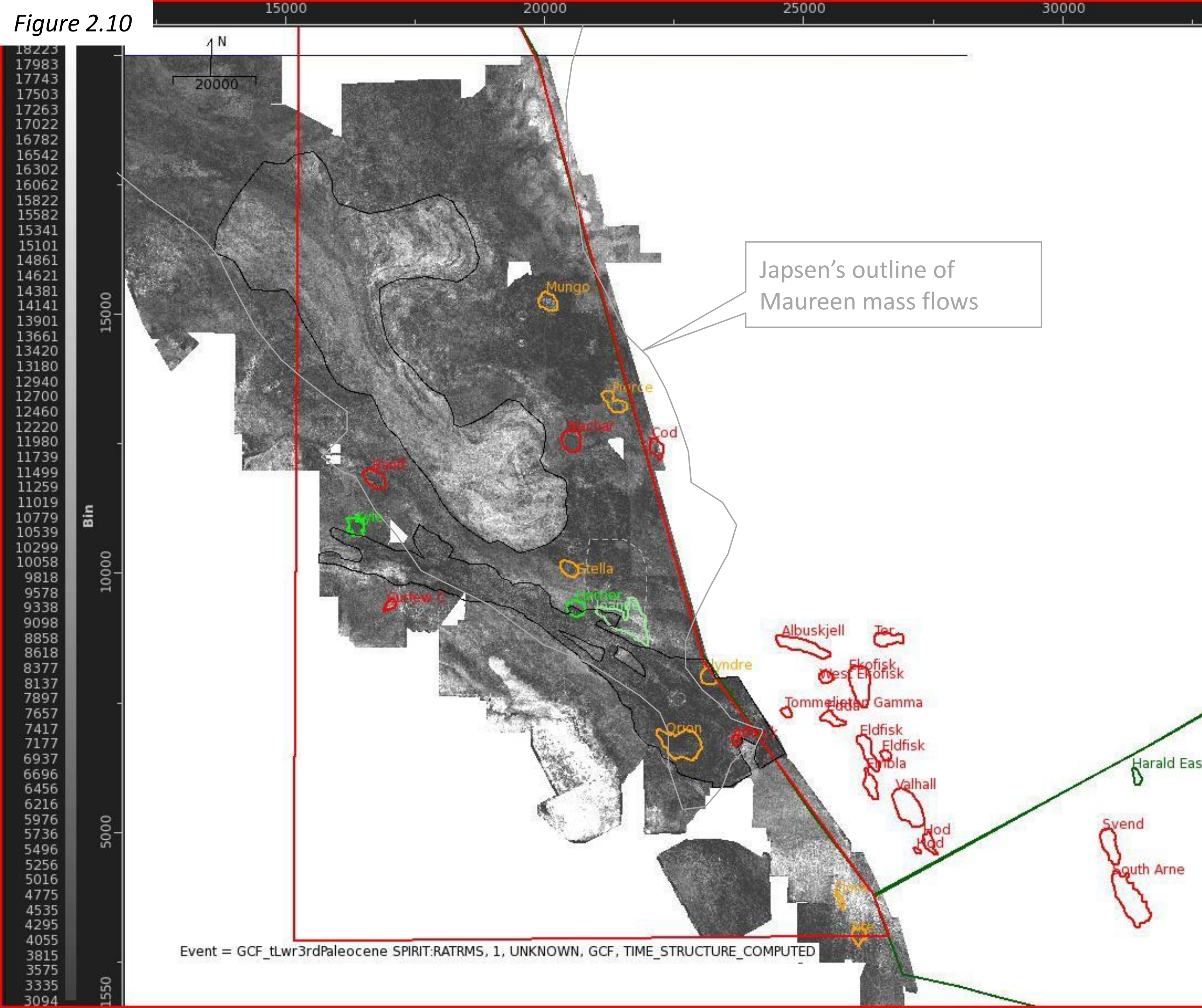

Japsen's outline of Maureen mass flows
Event = GCF_tSele-tChalk_isochr, UNKNOWN, GCF, TIME_STRUCTURE
Bin
N
20000
15000
20000
25000
30000
10000
5000
Machar
Cod
Banff
Harrier
Albuskjell
Tor
Ekofisk
West Ekofisk
Eldfisk
Valhall
Hod
Harald East
Svend
South Arne
Curlew C
Kyle
Mungo

Figure 2.10



Japsen's outline of Maureen mass flows
Mungo
Cod
Stella
Albuskjell
Tor
Ekofisk
West Ekofisk
Eldfisk
Valhall
Hod
Harald East
Svend
South Arne
Event = GCF_tLwr3rdPaleocene SPIRIT:RATRMS, 1, UNKNOWN, GCF, TIME_STRUCTURE_COMPUTED
Bin

3. Traps, charge and seal

Up to this point the report has dealt with chalk as a reservoir. I will now briefly discuss the other play elements: trap, charge and seal.

Trap It may be convenient to distinguish four main trapping styles in chalk:

- Rafts above salt diapirs - Machar, Banff
- Salt flanks - reworked slumps on the flanks of salt diapirs (Kyle, Mungo, Machar, Banff)
- 4-way dip above salt swells or inverted anticlines (Curlew C, Joanne, Orion, Affleck)
- Stratigraphic traps

Although I do not find the above distinction particularly helpful, it is useful to spend a few words on the chalk stratigraphic trap. In clastic settings, stratigraphic traps occur, among others, where sands shale out. There's hardly such a thing as shale out in chalk. In chalk, stratigraphic traps occur where chalk permeability decreases so much that capillary forces trap the hydrocarbons outside structural closure.

Although the chalk stratigraphic trap is rare (there is no example in the UK), most fields have an element of the 'capillary trap'. Tilted oil water contacts are the rule rather than the exception, and in low permeability chalk the FWL tends to follow structure.

The Danish Halfdan field, on the flank of the Dan field, is the classic example of a stratigraphic trap in the chalk. The Halfdan 'structure' indeed does not close, and laterally it is bounded by chalk of very low permeability, acting as a seal. Up dip, however, there is a continuous oil column from Halfdan up into Dan. Indeed, this is how Halfdan was discovered: not calling TD on a Dan well until saturations ran out.

Likewise, I know of no stratigraphic chalk trap in the North Sea that is not associated with a hydrocarbon accumulation in a structural closure up dip. In other words, it would be a first to find a North Sea chalk field in a stratigraphic trap in the absence of an associated structural accumulation up dip. Such a prospect on the UK side would be a very risky proposition indeed.

Charge typically enters via faults along salt domes and the Tor formation acting as a carrier bed. On the UK side, the source rock is the late Jurassic Kimmeridge Clay Fm, and on the Scandinavian side there are source rocks of equivalent age (Farsund Fm or equivalent).

Seal is provided by the uppermost Ekofisk layer and more importantly by the Paleogene shales, as long as these do not host thief sands (see section on porosity preservation).

4. Exploration strategy

4.1 Prospectivity of the lower chalk

As mentioned before, almost all North Sea chalk fields have their reservoir in the upper Tor and, to a lesser extent, the Ekofisk. This is not to say there are no shows in the Hod, Herring and Hidra. Quite the contrary, in the HPHT area there are numerous shows and kicks in these tight formations, which one would consider part of a seal rather than anything else. In the HPHT area, these formations are therefore considered a drilling risk. In many wells in this area, these formations have also been tested, with very poor results (see 2nd part of this report).

There is an exception where the lower chalk did flow above expectation. In 2012, an old exploration well, never abandoned, started to flow on the Elgin platform. I do not know what happened exactly, but it is thought that the Hod started to produce gas into the annulus and eventually the well head started to leak and the platform had to be evacuated. I do not know about flow-rates and volumes, but it is thought that the depletion and compaction of the underlying Fulmar reservoir opened fractures in the lower chalk that then started to flow. The mechanism where hydrocarbons are producible through geomechanically induced or re-opened fractures should also work on Franklin and Shearwater. Whether these can be exploited commercially remains to be seen.

From a seismic perspective, the Hod looks much more exciting than the Tor and Ekofisk. There are onlaps, amplitude changes, structures that look like channels etc. These may draw the eye of the interpreter but they do not necessarily indicate prospectivity.

It is therefore safe to say that the lower chalk (the Hod and below), is not a viable exploration target in the UK CNS.

4.2 Exploration of the upper chalk

Like in any other setting, exploration in chalk requires mapping of mature source rock, migration paths, traps and seals. Reservoir presence is the last piece. In clastic settings, this is about finding sand. In chalk it's not about finding chalk, as chalk presence is generally not the issue. It's about finding *porous* chalk.

On previous pages, I have argued that chalk porosity can be predicted from burial depth, overpressure and possibly early hydrocarbon presence. Obviously, this is not a very practical approach. Fortunately, there exists a powerful tool to map porosity in clean chalk. This tool is acoustic impedance, which I will discuss shortly.

With a porosity predictor in place, a tool to predict pore fluid fill would solve the puzzle. Unfortunately, fluid fill is more problematic to predict. In theory, there should be a (weak) AvO signal telling brine apart from oil and gas (see Japsen et al. 2004 for an AvO analysis over the South Arne field). Unfortunately, this has not been made to work in practice.

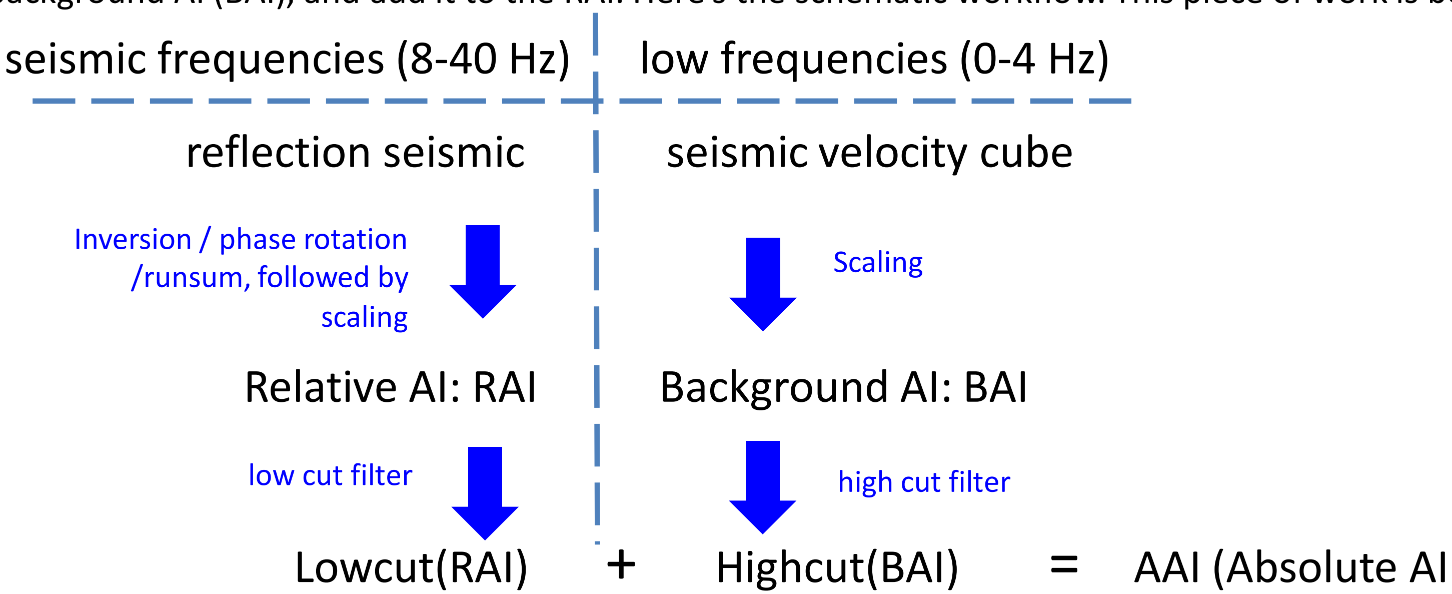
That's why Maersk and Shell are now testing Controlled Source ElectroMagnetic (CSEM) over Danish chalk. This method is also known as sea-bed logging, and is not treated in this report.

5. Porosity from seismic

5.1 Acoustic impedance

Chalk is abundant in the CNS, but only when it's porous enough (>25%), it forms a reservoir. Chalk porosity prediction is therefore key. As chalk, or at least the main reservoir unit (the Tor), is essentially monomineralic, the density and acoustic velocity depend strongly on porosity, and on nothing much else. Provided that the chalk is pure, a low acoustic impedance is therefore a good predictor of chalk porosity. Acoustic impedance (AI, the product of density and acoustic velocity) can be determined from seismic. This is a very well established method (e.g. Anderson 1999).

A few words on the generation of the AI cube. The seismic reflectivity cube can be inverted for relative acoustic impedance (RAI), for example by sparse spike inversion. This RAI cube basically has the same frequency content as the reflectivity (say 8-40Hz), and therefore lacks the low frequency part (the 'long wavelength' variations). Porosity prediction from AI is much more powerful when the AI also contains the low frequencies. So we need to be able to estimate the low frequency component, the background AI (BAI), and add it to the RAI. Here's the schematic workflow. This piece of work is best left to a geophysicist.



5.2 The background model

Roughly speaking, there are two sources of information that can be used to estimate the background AI: **well data** and **seismic velocities**.

When **well data** are used, impedances measured in wells are interpolated between wells. When looking for porous chalk, interpolating between wells may not be a very good idea. It's equivalent to finding sand by gridding up N/G data from a set of wells: you are not going to find the sand body unless it's already been drilled.

The alternative is to use **seismic velocities** as a source. Seismic velocity models are routinely built for seismic migration projects. They are derived from stacking velocities in PrSTM projects, or from tomographic inversion in PrSDM projects. Either way, the velocities are chosen such that they lead to flat gathers.

In the next section, we'll show how the AI cube is constructed for the HPHT dataset. Once the AI cube is constructed, it should be calibrated against well data: both logged AI and porosity.

There's one snag when using seismic velocities from PrSDM projects. These velocity models are constructed using a method called travel time inversion. This tomographic method needs an initial velocity model. And here lies the problem. Often, the initial model is created by interpolation of well velocities. Although in subsequent iterations, this model gets updated by the tomography where it gets 'seismic' input, a remnant of these well velocities will persist in the final model.

For 2 reasons, it's much better to have the seismic completely AI independent of well data. The first is already mentioned: you will not reveal the sweet porous low AI spot unless it's already been drilled. Second, calibration of the resulting AI and porosity cubes to well data will be biased as the well data was used for the construction of the AI cubes in the first place.

Much better to construct the initial model from stacking velocities or from Vo, k. I know this plea is lost to most processors (and interpreters), but I maintain the point nonetheless.

II.
Application to the HPHT dataset

6. Acoustic impedance and porosity from the HPHT dataset

6.1 The acoustic impedance cube

In the remainder of the report, I will apply the strategy outlined in part 1 to the HPHT area. The emphasis lies on chalk porosity prediction from Acoustic Impedance of the HPHT seismic dataset.

This HPHT seismic dataset R-2746 is the result of a PrSDM reprocessing in 2010/2011, over 4200 km^2 combining various acquisitions (McDonnell, 2011).

The following pages give a pictorial overview how the AI cube was constructed from the processing products. Included is the information required to reproduce the results.

Figure 6.1

1. Input: start with zero phase full stack reflection cube, better S/N than near substacks (0-13, 13-23 and 0-26 deg), although substacks have slightly better resolution
(volume R2746_10PrDMke_Full_T_Rzn_RMO_Deabs.3dv in OW proj HPHT_CNS)

Full stack reflectivity

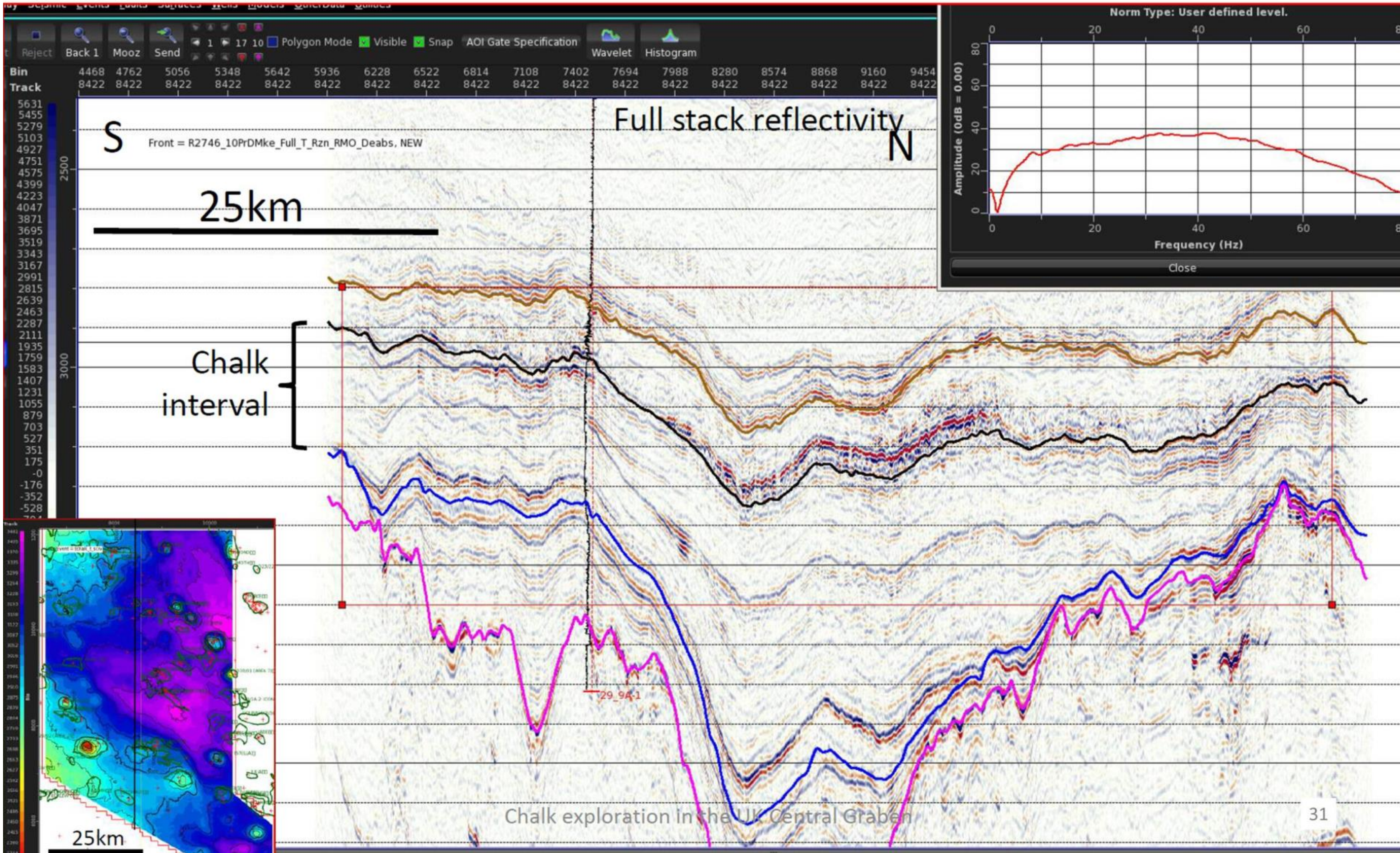


Figure 6.2

2. Runsum (Sipmap) the full stack with a slope of -6 dB/oct and lowcut start 0 Hz and lowcut end at 4 Hz. The sipmap runsum operator rotates the phase by 90 and boosts the lower frequencies.
3. Scale (multiply) the runsum with a factor 0.4 to give correct units (m/s g/cc) (parameter derived on well 29/9C-8)

RAI (Relative Acoustic Impedance)

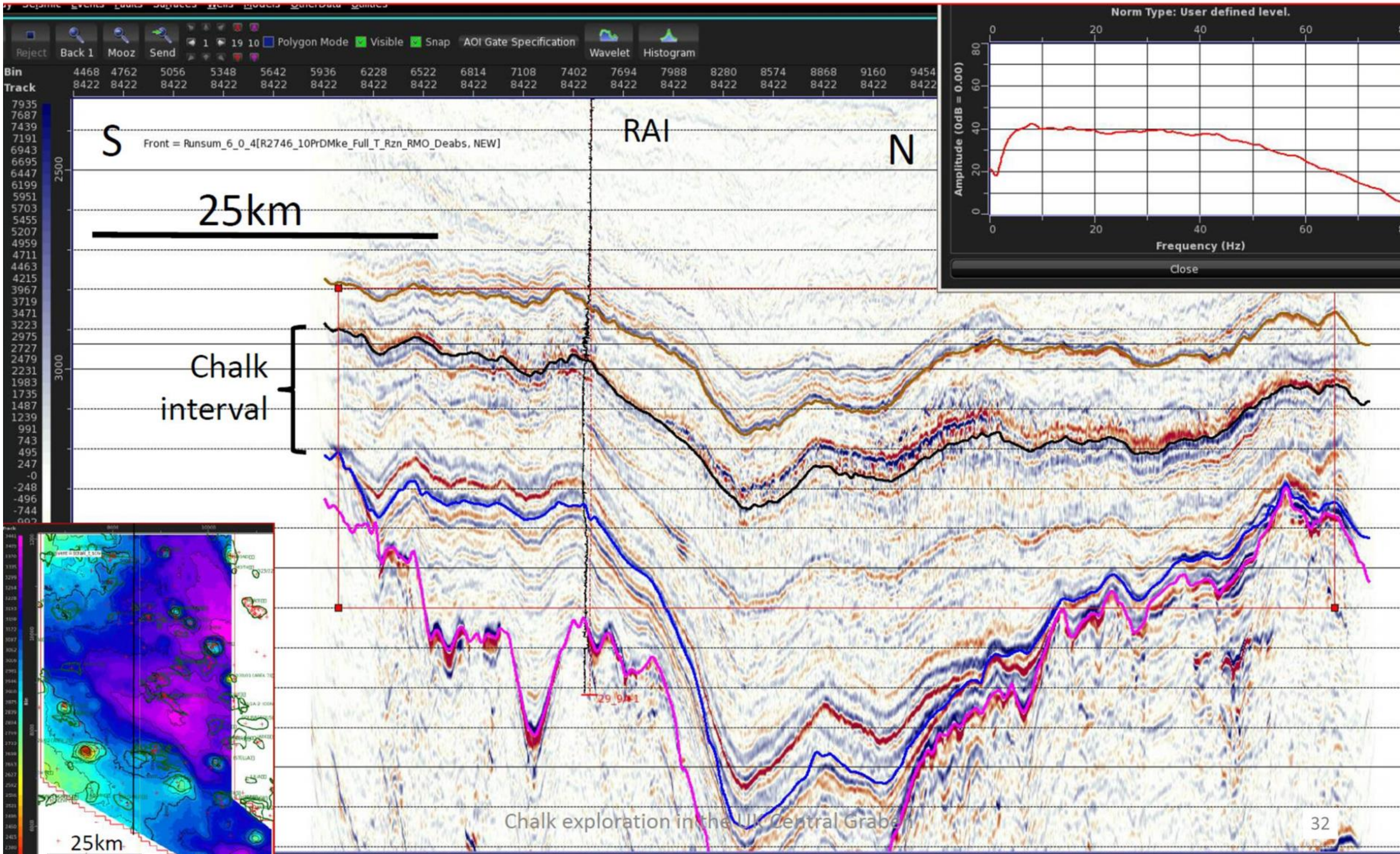


Figure 6.3

4. Lowcut filter RAI (start 4, end 8 Hz)

Lowcut (RAI)

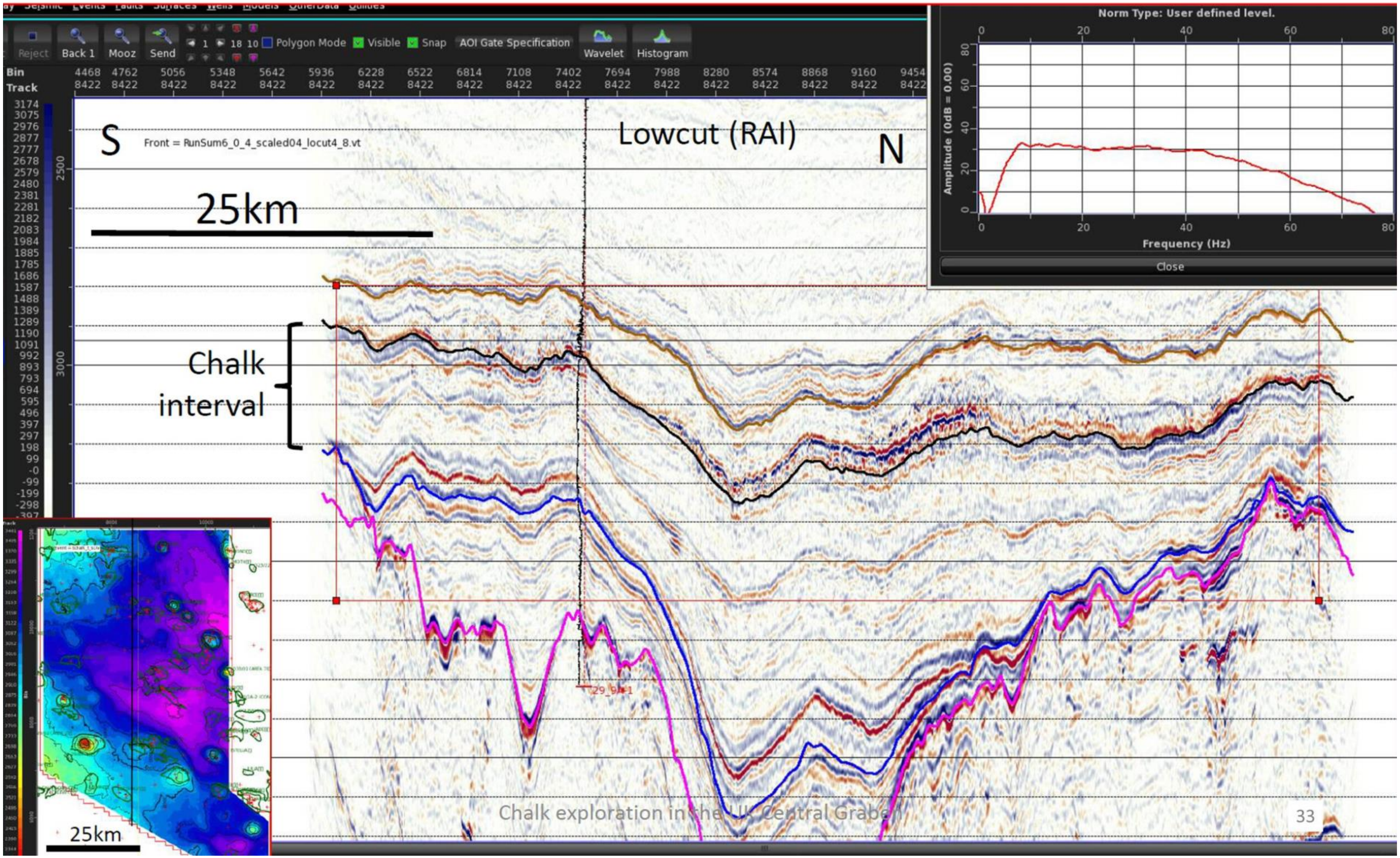


Figure 6.4

5. Take PSDM migration velocity model (model E)
(/glb/eu/sukep/data/gs03/cnns/hpht_cns/123di/Velocity/
hpht10_modelE_tv_100x100x8.bin)

Velocity model

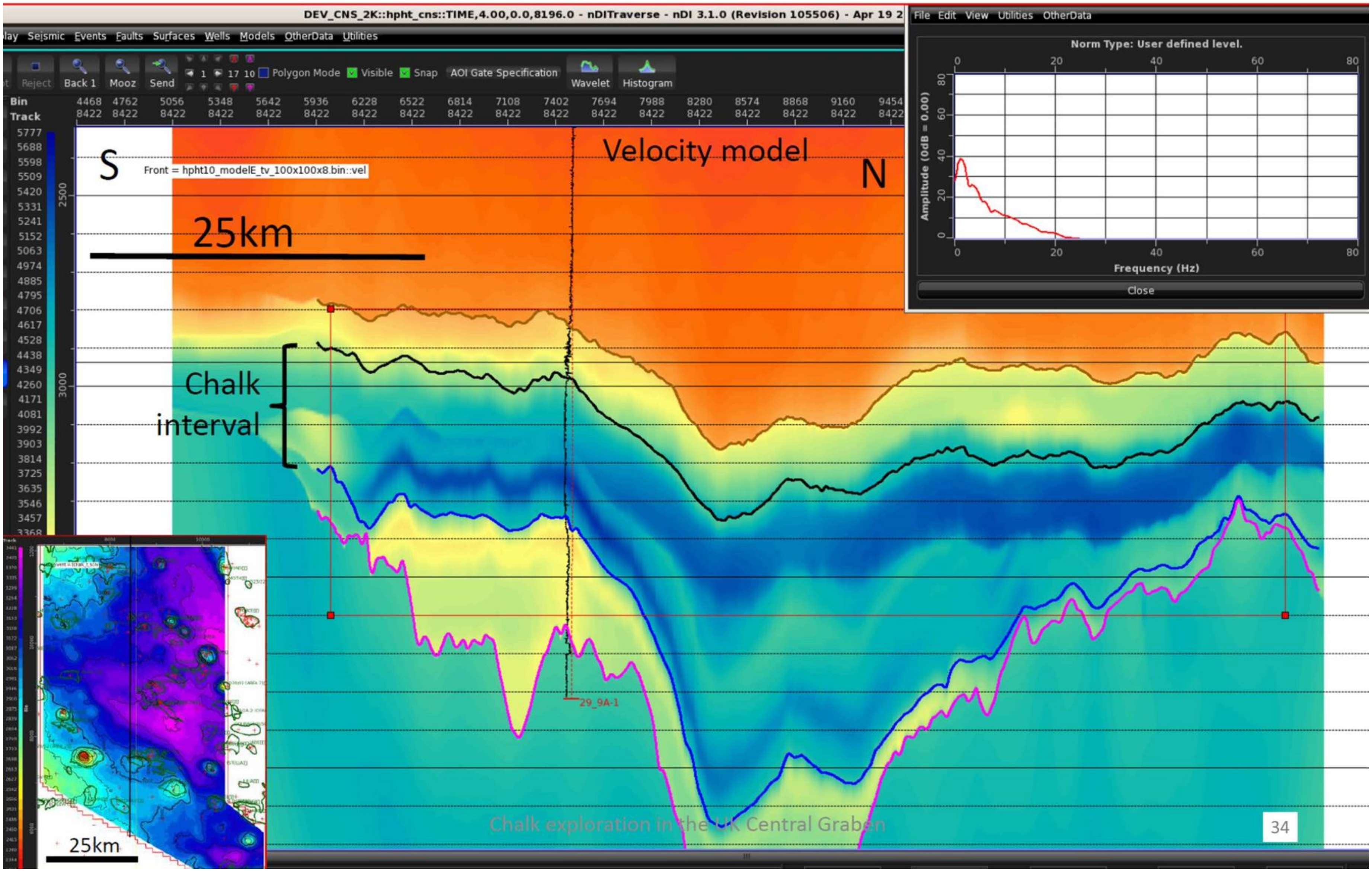


Figure 6.5

6. Scale (multiply) the velocity with a factor 2.45 (density) to give correct units (m/s g/cc), (parameter derived on well 29/9C-8)
7. Highcut filter BAI (start 4, end 8 Hz)

Highcut (BAI)

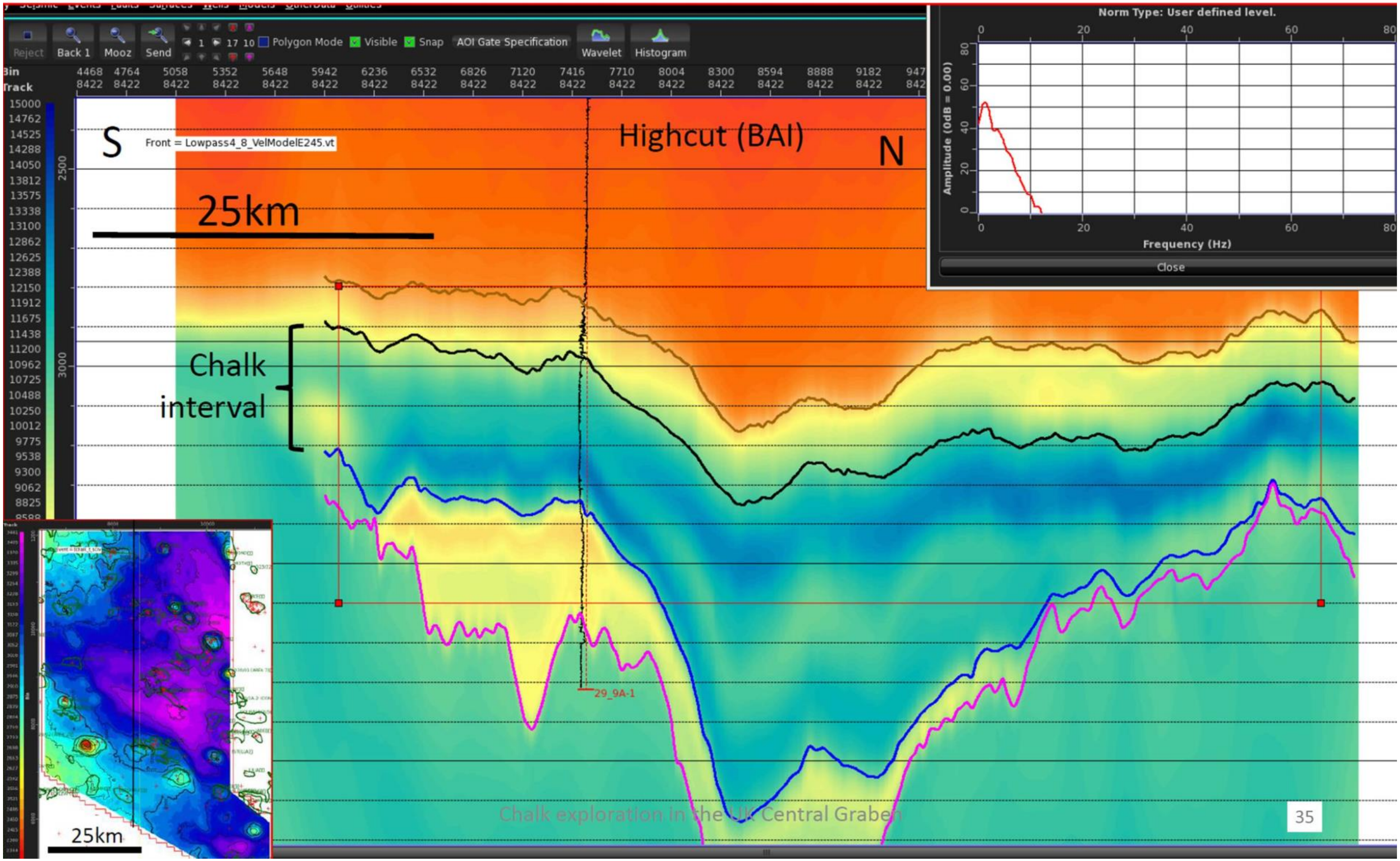
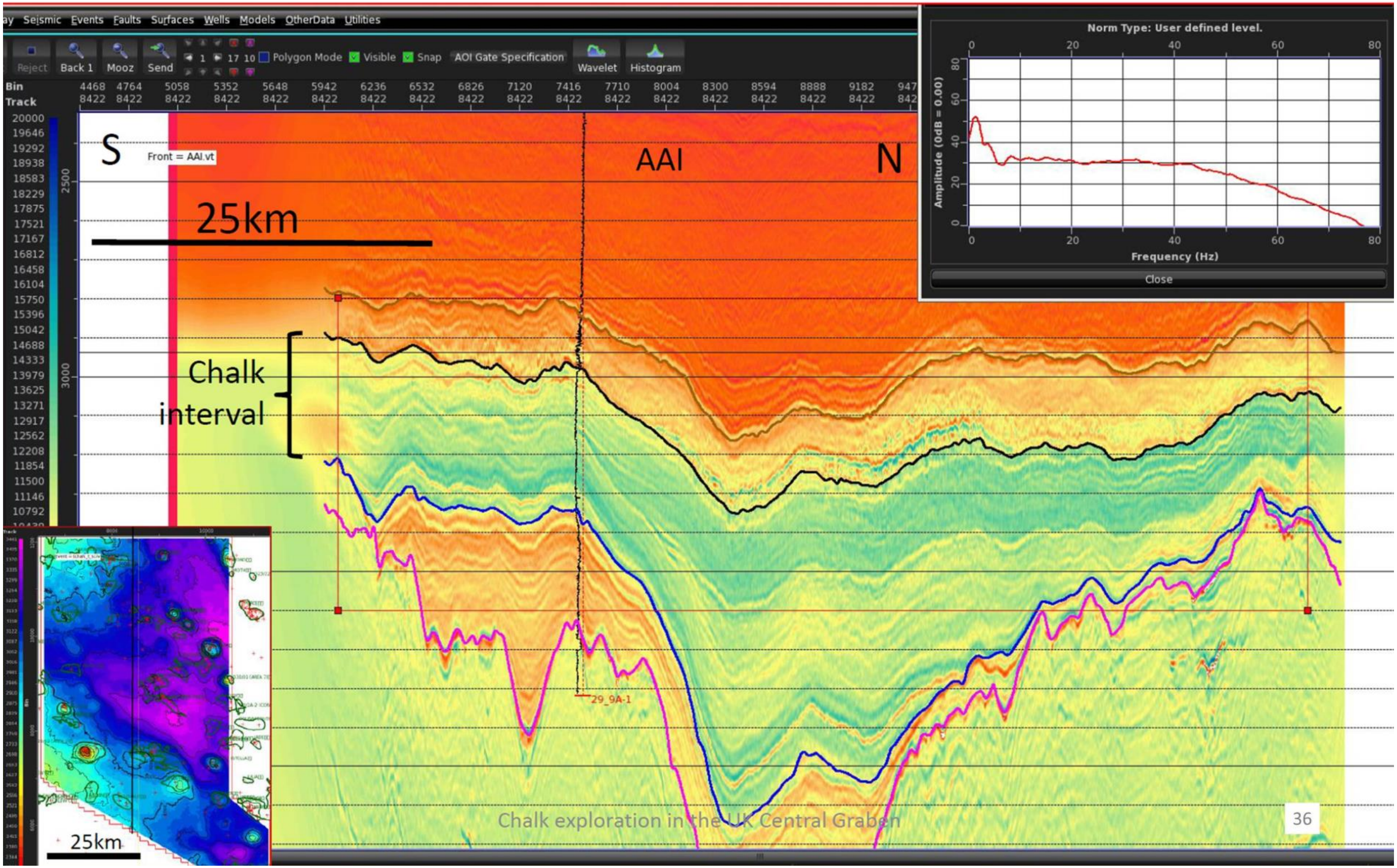


Figure 6.6

Final step: lowcut(RAI) + highcut(BAI) = AAI (Absolute Acoustic Impedance)

cube in: /glb/eu/sukep/data/gs03/cnns/hpht_cns/123di/Velocity/AAI.vt



6.2 Calibration of the AI dataset

Once the seismic AAI cube is constructed, it should be calibrated against logged AI and porosity. It is advisable that the logs be high-cut (low-pass) filtered to seismic resolution. Also, the logged AI should be compared against logged porosity for reference. Of course, all this requires editing and QC of the density, sonic and porosity logs. The porosity log is a derived log, and it is usually not available over the chalk interval. This is indeed the case for the vast majority of wells in the HPHT area.

From the HPHT chalk AAI cube I extracted two maps: minimum and average AAI in an approximate Tor interval. Top and base Tor were not interpreted, instead a window between tChalk+12 ms and tChalk+56 ms was taken. Maps on next page.

For calibration, I computed the maximum Tor porosity from density logs in wells 29/8a-3, 29/8b-2, and 29/9a-1. I picked the 20 ft interval with lowest density in the Tor and determined the average density over that interval, which I converted to porosity. Two of the wells have a petrophysical evaluation and a miniplot, from which I read off the porosity. I compared these data to the minimum Tor AAI, which I read off from the map. The table and plot in figure 6.9 present the result:

$$\phi = 0.70 - 5.4\ 10^{-5}\ \mathrm{AAI}$$

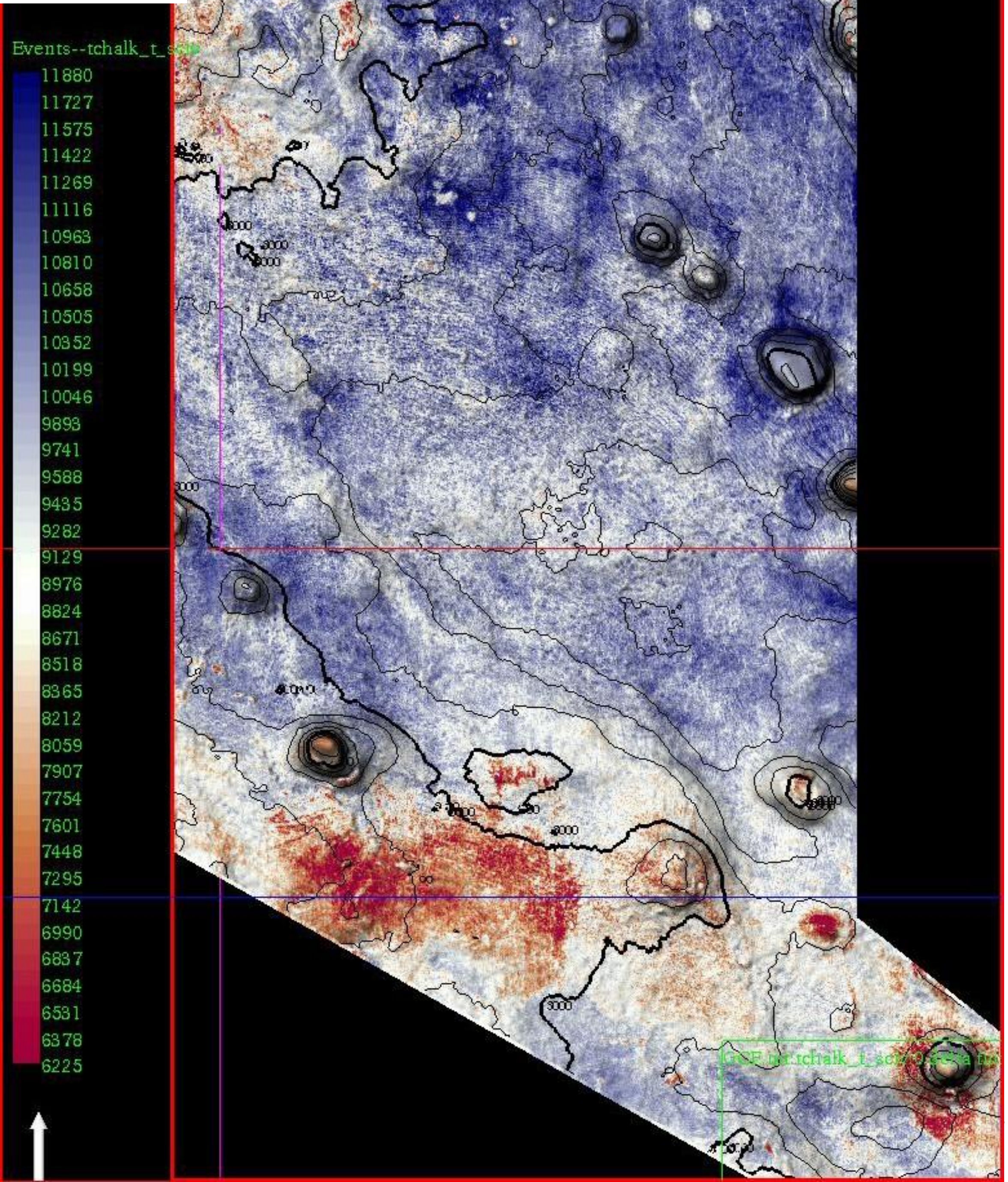
I realise that a calibration based on 3 data points is meagre. In the absence of proper porosity evaluation it should suffice, as long as we put the porosity maps to qualitative use only.

For comparison, I’ve shown a few graphs on the AAI-porosity calibration of the Tyra field in the Danish Central Graben (figure 6.10). The plot in the lower left shows the HPHT from this study against the Tyra data. The trends are not identical, but close enough to inspire trust in the qualitative use in the HPHT data.

Two more remarks on the calibration of the AAI cube. First, in the northeast of the HPHT area, there's an area of low impedance penetrated by well 22/23a-2. This well encountered relatively high clay content in a thick (220') Ekofisk. The low AAI does not reflect a high porosity, but instead is a consequence of the high clay content. Second, seismic image and amplitude fidelity at steep salt diapirs is often low. As the seismic amplitudes in such areas are week and unreliable, the AAI cannot be trusted. A good example is the Machar field.

The appendix discusses some issues with velocity model E. Velocities above the just above the chalk and just below the Base Cretaceous Unconformity appear too high.

Figure 6.7



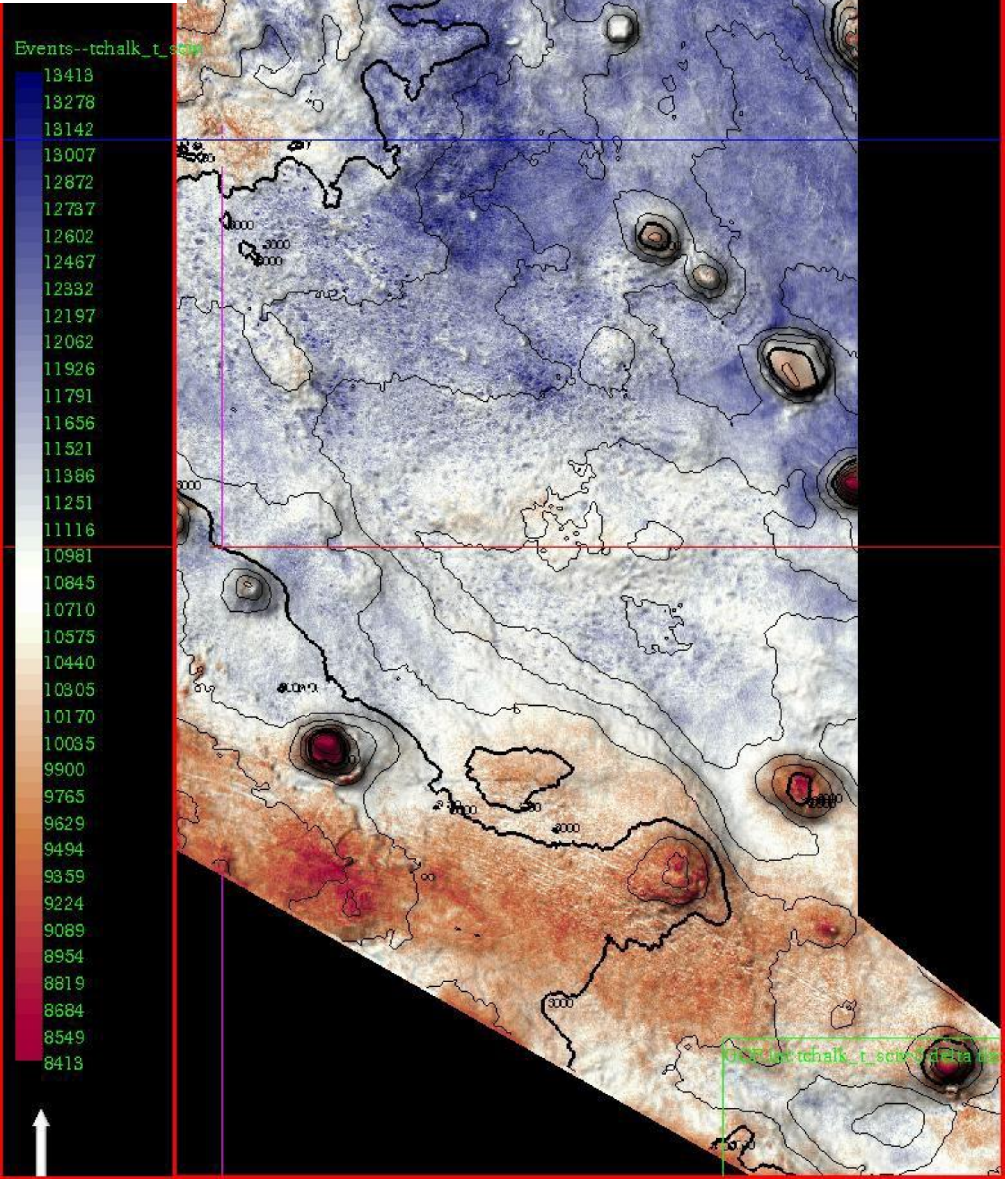
Surface: top Chalk

contours: top Chalk

draped attribute: minimum AAI in approx. Tor window (tChalk+12 to tChalk+56)

A pattern not unlike a massive fingerprint can be discerned in the northern half of the map.

Figure 6.8



Surface: top Chalk

contours: top Chalk

draped attribute: average AAI in approx. Tor window (tChalk+12 to tChalk+56)

Semicircular features of high impedance can be seen in a band across the middle of the map.

Figure 6.9

Calibration of seismic impedance against logged impedance and porosity

											seismic AAI
			density				porosity				from Tor map
well	area	dt	bulk	fluid	vp	logged AI	from densit	miniplot	phi (use)		min AAI
		[ms/ft]	[g/cc]	[g/cc]	[m/s]	[m/s g/cc]	[-]	[-]	[-]		[m/s g/cc]
29/8B-2	acorn		2.20	1		0	0.30	0.30	0.30	peak	
29/9A-1	puffin		2.18	0.82		0	0.28	0.29	0.29	peak	
29/8A-3	acorn	90	2.14	1.05	3387	7234	0.35		0.35	20 ft avg	6466
29/8B-2	acorn	86	2.26	1	3544	8010	0.26	0.26	0.26	20 ft avg	7911
29/9A-1	puffin	80	2.22	0.82	3810	8458	0.26	0.26	0.26	20 ft avg	8153

mineral density 2.71 g/cc

$$\Phi = (\rho_M - \rho_B) / (\rho_M - \rho_F)$$

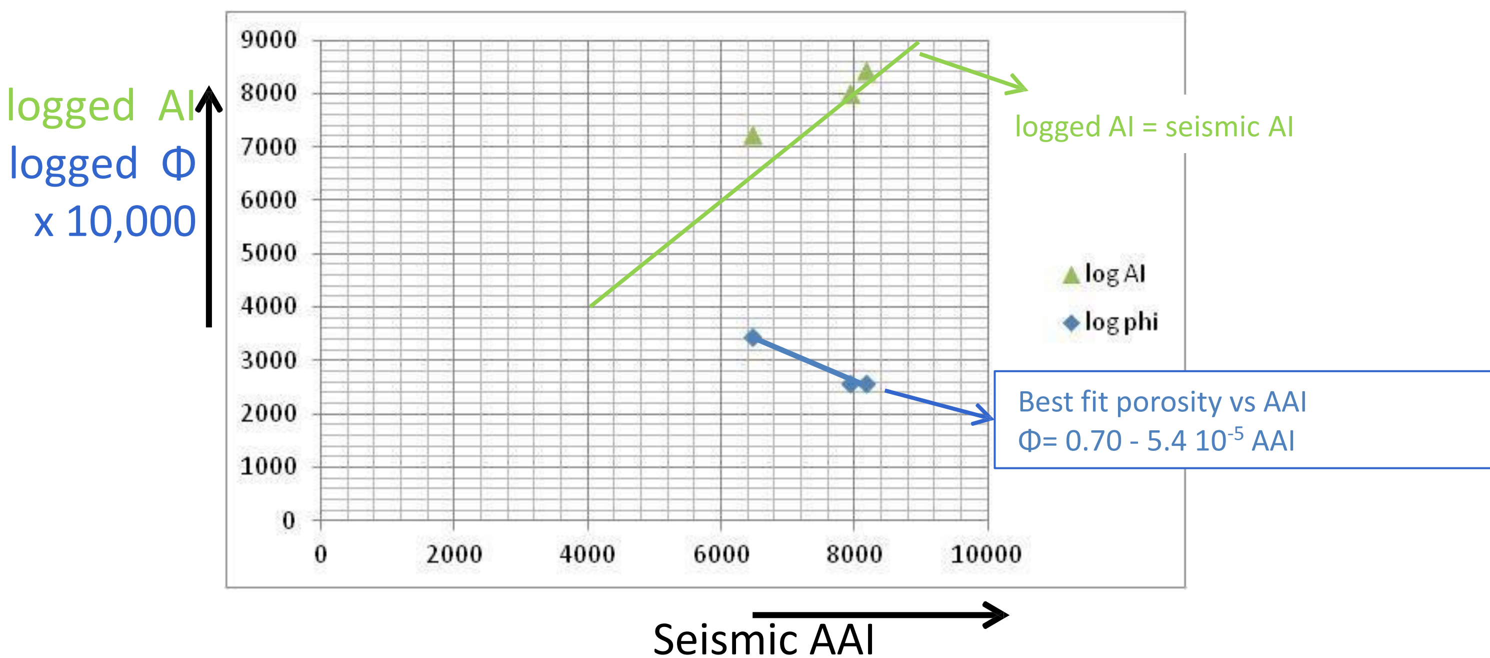
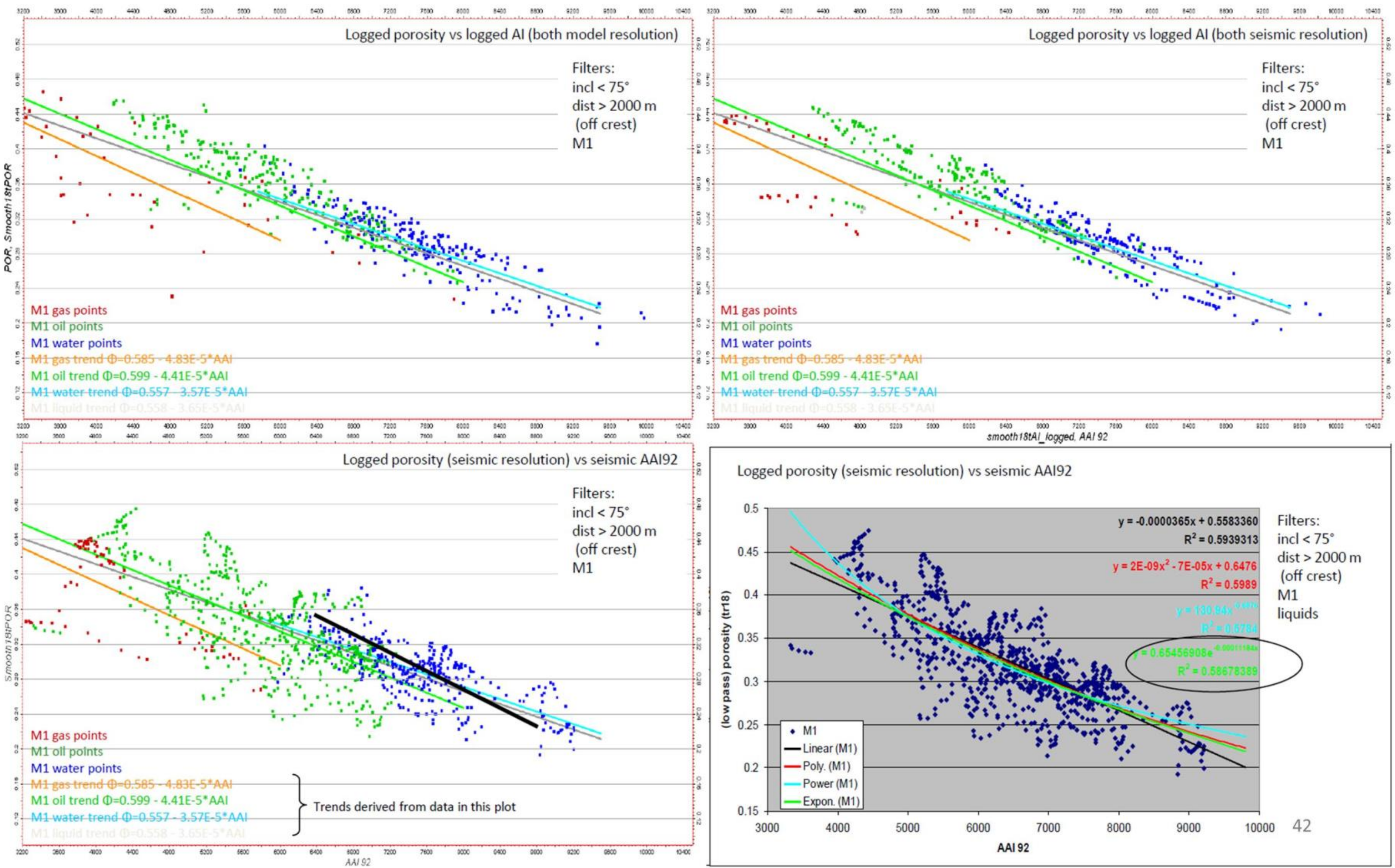


Figure 6.10

Upper Tor porosity vs AI calibration for Tyra field (Denmark), Plot in lower left has trend from this study in black line



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