Integrated seismic geomorphology as a tool to unravel fluid expulsion episodes expressed in the sedimentary record in a mature petroleum basin
(Danish Central Graben, North Sea)

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Highlights
- Recessional pushouts and seep carbonates within the Cretaceous of the Danish-North Sea and an explanation of their spatial and stratigraphic occurrence with the use of integrated seismic and wireline data analyses.
- Features are concentrated at the top of the inverted foredeep (the chalk group) and exhibit mainly seep carbonate and other organic-rich muds at the base of the Cretaceous.
- Small-scale structural features such as normal faults and synsedimentary grabens are also observed in the Paleocene.
- The Cretaceous sequence is divided into four main subunits based on the distribution of seep carbonates and organic-rich muds.
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I. Where?
- Focus on the Cretaceous of the Danish North Sea (post-rift strata), which is underlain by deeply rooted Late Jurassic faults that offset organic-rich shale intervals and became inverted during the Mid-Cretaceous (Campanian). The Cretaceous sequence is divided into four main subunits based on the distribution of seep carbonates and organic-rich muds.

II. What?
- Cat. 2: small/middle circular depressions (100-180 m across, 10-20 m deep)
- Cat. 3: large/giant circular to complex depressions (100-500 m in diameter, 10-70 m deep)
- Cat. 4: mega basin-shaped depressions (500-1000 m in diameter, 50-400 m deep)
- Cat. 5: fault-bound high-amplitude reflective packages (isochrons) - consistent with high defectivity (100 m)

III. Features strongly linked to deeply rooted faults and on top inverted structure

IV. Why?
- Generation of gas-bearing fluids from thermogenic and/or fermentative processes may have led to gas expansion and fault failure, leading to formation of gas-bearing fault to the highest parts of the basin.
- Continued seepage and episodic migration of seep carbonates and giant chalks (see V).

V. Evidence of recurring episodes
- Continued seepage and episodic migration of seep carbonates and giant chalks (see V).
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VI. How? Proposed fluid migration history

Tectono-strat stratified model

Pre-inversion (Time 1)
1. Entrapment of gas within pre-Chalk Group strata, small gas by-passes present within pre-inversion strata.

Syn-inversion (Time 2)
2. Major expulsion during last part of Chalk Group deposition (Danian) to form giant chalks.
3. Seepage of methane out of Chalk Group through palaeo-faults to form small gas and carbonates within overburden.

Post-inversion (Time 3 and 4)
- Continued expulsion causing smaller pushouts to form.
- Major exploitation during last part of Chalk Group deposition (Danian) to form giant chalks.
- Seepage of methane out of Chalk Group through palaeo-faults to form small gas and carbonates within overburden.

Implications
- Demonstration of close integration of tectono-stratigraphy, seismic geomorphology, and basin modeling data to show correlation of source rock maturity, fluid migration pathways, and expulsion expression within the sediment.
- Giant outcrops of fluid already during chalk deposition in relation to tectonic activity, providing maturity of the main source rock for the CPG and B-Member of the upper Jurassic.
- Mega pushouts show large overlap with present-day hydrocarbon accumulation. This reflects an overlapped expulsion phase that provides insights into a long-lived migration pathways.

Applications
- Exploration for hydrocarbons based on mapping of pushouts and seep carbonates within the North Sea Basin with integrated approaches.
- Pushout fill by complex reservoirs with remanent facies, small gas by-passes, carbonate chimneys, and small clasts.
- Seep carbonates form early cemented intervals that act as baffles for migrating hydrocarbons.