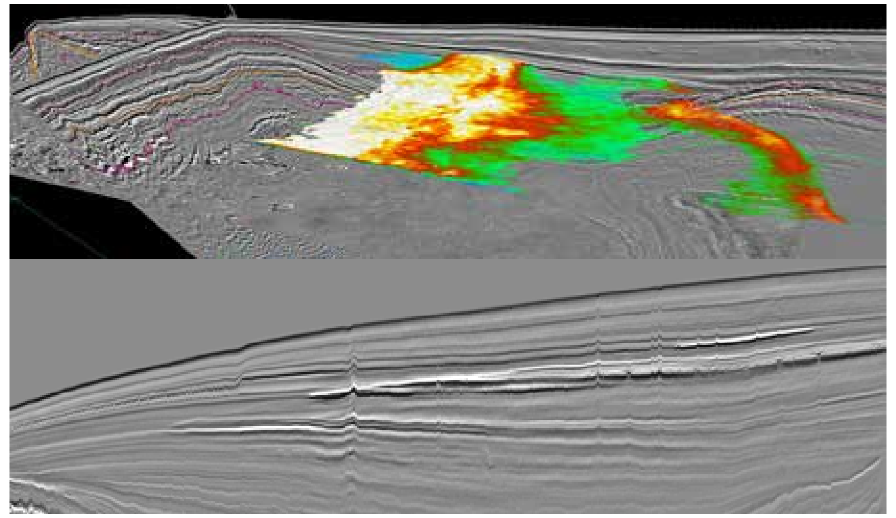
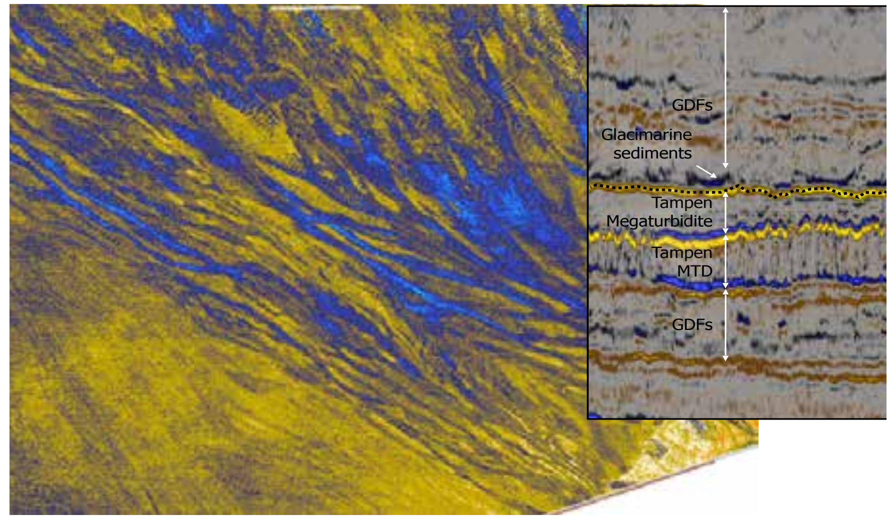
The ambitious search for more gas

Huge areas remain underexplored in the Norwegian Sea. Now is the time to find gas in vast quantities. But do not forget there is a fair chance to discover oil. Here are some potential play models that need to be investigated further.

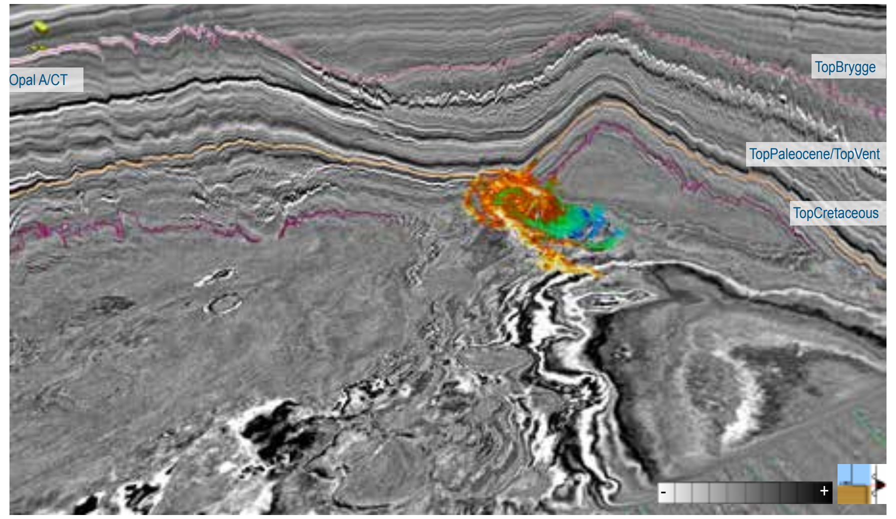
TGS



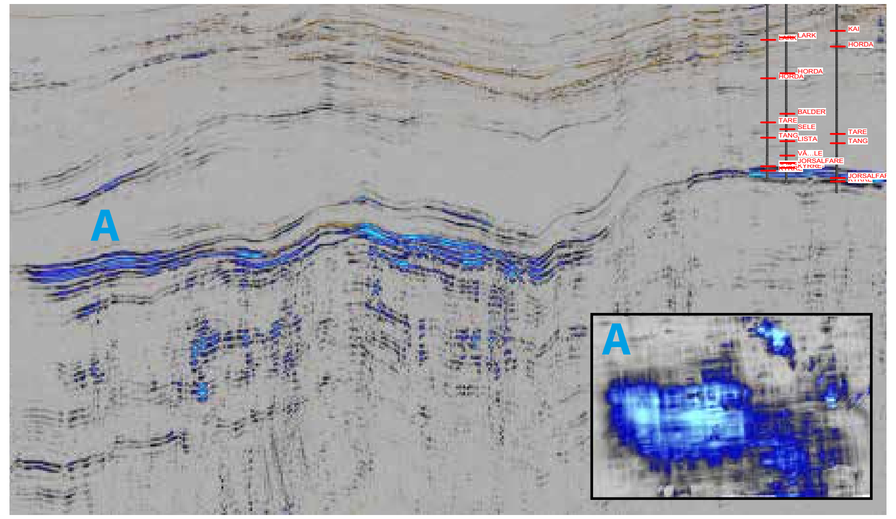
1. New shallow play model: In a vast area (>2,500 km²) west of the Helland-Hansen dome we have stacked bright events in the Upper Miocene and lower Plio-Pleistocene package. Phase-inverse amplitude reflections should represent shallow gas below the gas hydrate stability zone. If it is possible to produce from these units, then the volumes of gas present could be huge.



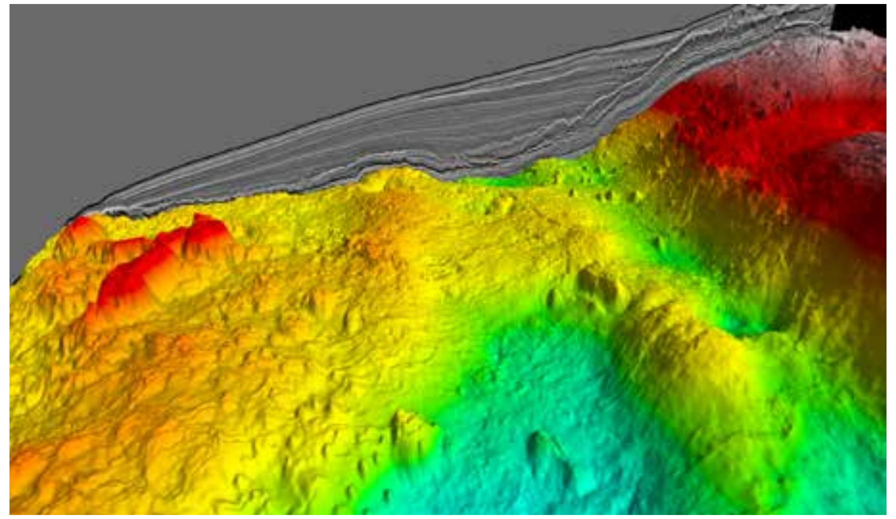
2. New shallow play model: Shallow gas accumulations in glaci-marine sands deposited as gravity flow deposits (turbidites). Due to great thickness of the Pliocene and Pleistocene sediments any gas trapped in deeper stratified traps may have enough pressure for commercial aspects.



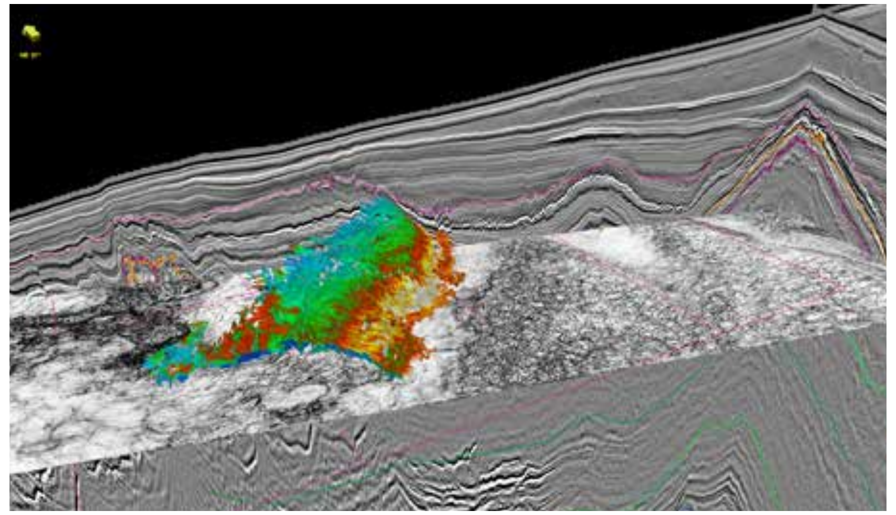
3. One of many anomalies within the Eocene package west of Helland Hansen dome. This 65 km² size lead sits in the syncline between the "Middle dome" and the Modgunn Dome to the left. The amplitude anomaly corresponds to a structural trap created by a hydrothermal vent system from a deeper volcanic sill intrusion.



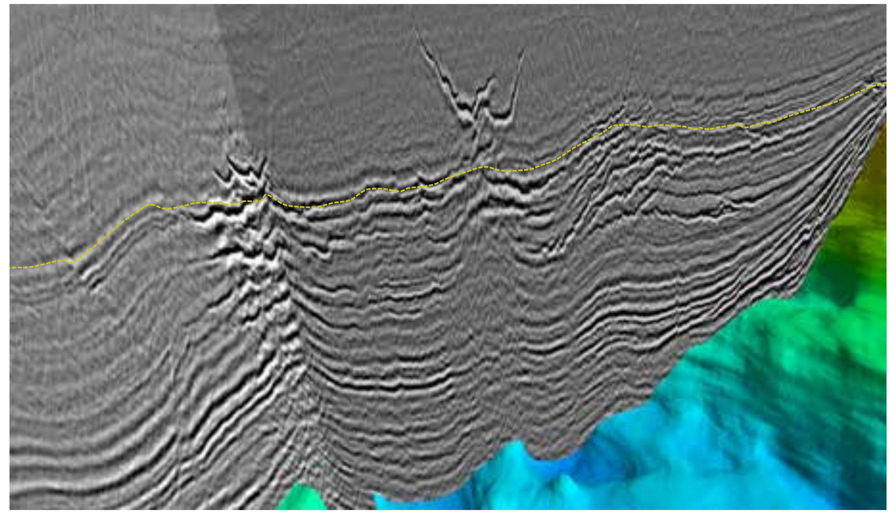
4. Arbitrary line within the TGS/Spectrum J-Cube tying the Ormen Lange field in the east (right) and out in the AM18 area in the west highlighting class 3 AVO trends (Far-Near*Far, blue). The amplitudes within lead A show excellent correlation with the gas-filled Egga sands in the Ormen Lange. Inset: Lead A indicates an anomaly in excess of 300 km².



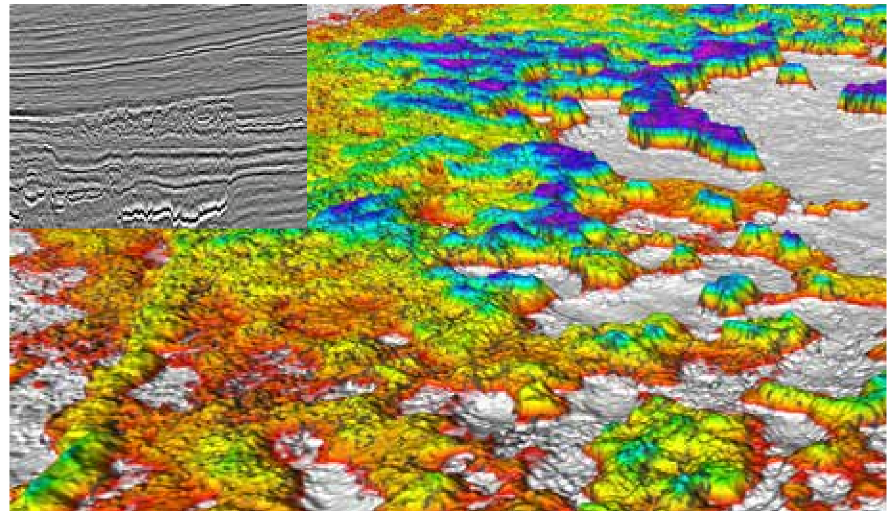
5. Huge untested domes with potential in the Upper Cretaceous Springar Fm, Paleocene and Eocene. To the left the Modgunn Dome passing the "Middle dome and to the western flank of Helland-Hansen (right) Above these domes we have potential shallow gas shown in figure 1. An Early Eocene surface is shown.



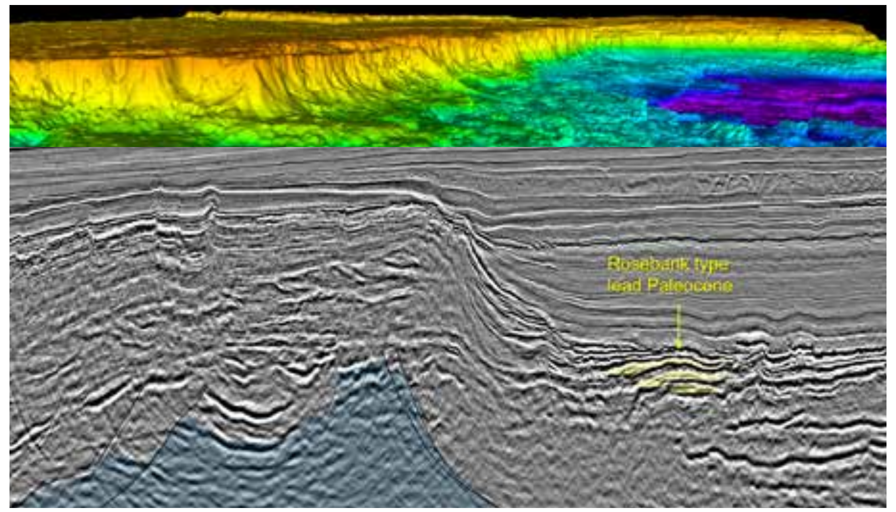
6. Paleocene bright amplitude trend (yellow) on the eastern flank of the Modgunn High. As a rule, we observe bright amplitudes only on the flanks of the inverted domes within the Upper Cretaceous to Eocene interval. Subtle thickness variations, with thinning over the top of domes, indicate structural barriers for the gravity flow deposits in the same interval. Bright class 3 AVO trends is found as doughnuts around the drilled domes, i.e. Solsikke, Havsule, Edvarda and as seen in figure 4 surrounding Vigra High.



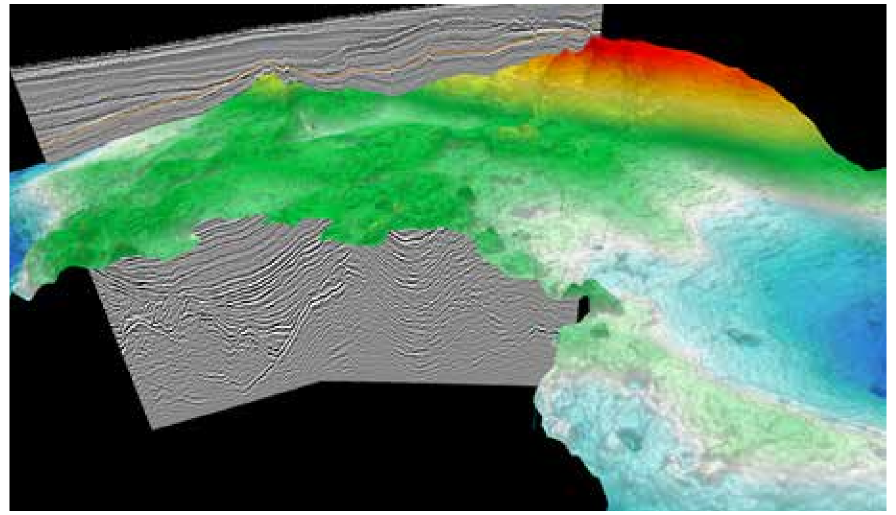
7. The Lower-Mid Cretaceous is highly reflective suggesting the presence of sands interfingered with a proven "good" marine source rocks (TOC 1-1,5 & 300-1100 HI in the Helland Hansen well). The volcanic sills intruding the Blålange Fm create anticlinal structures, secondary porosity and the heat from the sill can produce hydrocarbons. The Blålange FM was still immature as a source rock when sills intruded in Late Palaeocene. Mid-Turonian (Lysing/Blålange) shown as a dashed line; BCU shown as a surface.



8. New play model for the southern Møre Basin: In the slope down from Tampen we interpret a vast area of Eocene sand injectites. The biggest communicating injectites are >50 km² and have a soft amplitude anomaly in the top. Interpreted top of injectite facies showing time thickness of facies blended with facies variance. Inset shows intrusive geometry of facies in profile.



9. One of many leads (Rosebank type) interpreted as Paleocene sands between thin lava flows. These are found in the front of the volcano-clastic delta sitting over the Møre Marginal Plateau. Soft anomalies and potential flat spots defines this multi layered lead. Shaded in blue is the rotated fault geometries observed sub-basalt. Inset in the top shows top basalt escarpment along the Møre Marginal Plateau.



10. The Rån Ridge is interpreted as an uplifted Triassic-Jurassic depocenter sealed by the Base Cretaceous Unconformity. Between the highs we interpret entry points for Palaeocene gravity flow fan complexes with a proximal position around the Rån ridge. Tilted fault blocks are controlled by a decollement layer. The depocenter is reachable by exploration wells. 3D view shows Top Cretaceous gridded horizon.

ANNONSØRINNHOLD

Europe Needs More Gas: Exploring the Atlantic Margin with 3D Seismic

Bearing in mind that the Norwegian gas production is falling, the Møre and Vøring basins emerge as promising places to explore for additional gas resources.

In 2017 TGS started the biggest seismic 3D campaign in Europe to date. With only 4 wildcats within a survey area equivalent to 5-6 North Sea quadrants, these provinces of the Norwegian Sea are certainly immature with respect to exploration.

The area covered with new 3D has water depths from 500 to 2500 meters.

Drilling has so far proven oil and gas in Upper Cretaceous and Paleocene units. Also, based on the **Ellida** and **Havsule** well results, there is no doubt that an active oil source is present in the Møre Basin. However, the common expectation is gas.

The **Ormen Lange** field, discovered in 1997, supplies 20% of the natural gas consumption of the UK. We also know that Norway exported record high gas volumes to Europe in 2017, meaning that market interest for gas is rising. Europe is concerned about Norwegian gas deliveries, especially after 2025, as it is prognosed that Norway will get a marked decline in production.

Geological framework

The Møre and southern Vøring basins are both filled with thick Cretaceous and Tertiary successions.

The main reservoir facies in the current play models is gravity-driven **turbidites**. From Cretaceous to Paleocene they were sourced from both the Greenland and Norwegian side.

The last **rifting** phase in the Møre Basin was Late Jurassic to Early Cretaceous. From Cretaceous to Paleocene, extension stepped northwards and ceased in the northern Vøring Basin with breakup and onset of continental drift at 55 MA.

A change in the spreading axis in the NE Atlantic during Late Oligocene resulted in large-scale **compression** over the conjugate Norwegian and Greenland margins, creating large domes with inverted Cretaceous and Paleocene basins.

Interpretation of the **Møre Marginal Plateau** in the southwest has previously been limited to gravimetric data. Now, with the help of new 3D seismic data, shallowing of the base Cretaceous into the oil window and rotated fault blocks below basalt can be observed.

Another important feature is the **Jan Mayen** lineament that comes into the northern survey area AMN17. Observations support a hypothesis that the lineament splays out, offsetting deep basement highs and setting up possible pull-apart basins. This could mean local thick source rocks in Albian/Aptian and Turonian times and thicker reservoir units in Upper Cretaceous. We have observations of such local thickness anomalies in the southern Vøring Basin, vest of the Helland Hansen dome.

To the southeast, down-dip from the Tampen area in the North Sea, a thick succession of sediments was deposited in the Plio-Pleistocene (the North Sea fan). The thick overburden could create efficient pressure to make potential gas trapped in Paleocene units below into commercial targets (See fig 2).

The basins in the western parts of the survey areas are influenced by **flood basalts** and **shallow sill intrusions**, whereas sills are typically found in the Lower Cretaceous towards the east. The volcanic rocks may have played a vital part in the petroleum systems found in this area. For example, a sill intrusion or a volcanic complex may alter the rhyology (stiffness) of the basin locally and asymmetrical subsidence follows. This may generate anticlinal structures that can trap hydrocarbons.

When the sill intrusions penetrate **organic rich rocks**, like the Blålange Fm in this area, it could produce very large amounts of oil and gas. It may also generate secondary porosity in an otherwise tight mud-dominated basin and vertical migration pathways in form of hydrothermal vents. The sill complexes could then create hydrocarbons, secondary porosity, migration pathways and structural closures (ref. the Tulipan and recent Balderbrå discoveries).

One of the challenges with hydrocarbon exploration in volcanic basins is the sub basalt seismic imaging. TGS intends to take on this challenge with the AM17 project.

The areas west and southwest of Ormen Lange have barely been explored. The **Tulipan** gas discovery is the only well in the 30 000 km2 large Møre Basin. The Tulipan well intersected pay in Danian age sands deposited in a large Paleocene turbidite fan complex most likely sourced from the Greenland side of the young Atlantic Ocean. Paleocene is a key reservoir interval for these areas, but hydrocarbons have also been found in silty sands of the Upper Cretaceous as in the **Ellida** discovery. It has been a challenge to find well-developed reservoir units, although the well density so far is very low.

Almost all of the wells drilled in deep water in the Norwegian Sea have targeted large anticlinal domes created by inversion in Late Oligocene to Miocene times. The new data reveals subtle highs over the same domes creating barriers to gravity-driven sedimentation during Late Cretaceous and Palaeocene times.

This means that the best reservoirs may sit in the synclines and create donut-shaped stratigraphic traps around the same domes.

BENT KJØLHAMAR

New play ideas

An extension to the original Atlantic Margin 3D programme, supported by industry funding, will provide new 3D seismic close to and west of the **Ormen Lange** gas field.

The main reservoir in this gigantic field comes from Palaeocene gravity flow deposits (turbidites) sourced from Norway. Based on amplitude responses and AVO anomalies in 2D data, we believe that a major part of the Palaeocene and Upper Cretaceous turbidite flows bypassed south of the Ormen Lange area and was deposited further west and north.

The **Vigra High**, located 50km west of Ormen Lange, is different from other highs as no major inverted dome is seen over and east of it. We observe large thickness variations in the Palaeocene interval, thinning over the Vigra High. We observe AVO anomalies (Class 3 trends) surrounding the high – but not over it. In map view, these bright units create a donut shape surrounding the pre-Cretaceous high sitting deep below. Several bright amplitude anomalies in the slope down from Ormen Lange also give hope for stratigraphic traps closer to the field (see Fig 4).

Similar observations are made surrounding the drilled prospects called **Havsule**, **Solsikke** and **Edvarda** – all drilled on top of the inverted domes. It is quite striking that none of these wells - positioned on top of the inverted domes - have apparent brightening at any levels. On the giant Helland-Hansen dome (10,000 km²) - drilled by Shell in 1998 – we observe strong amplitude anomalies in Upper Cretaceous and Palaeocene on the western side of the segmented dome. We might have to drill all the domes again, but then the flanks must be in focus (See fig 6).

Shallow anomalies

Several more exotic play models are also looked at within the area. In the AMN17 survey west of the Helland-Hansen dome, shallow bright-amplitude anomalies are observed in the upper Miocene and lower Plio-Pleistocene (see fig 1). In this play, gas hydrates may act as seal trapping free gas in a very large 3-way closed structure. Sharp amplitude anomalies (free gas?) with upper cut-off correlating to the gas hydrates stability zone in the west are seen over large areas and within three seismic events. A special 2 ms high-resolution seismic volume is ready to investigate this further.

Possible injectites

In the slope north of the Tampen area in the North Sea we observe large elongated mounds with a chaotic interior (see fig 8). Looking closer at the fast-track AMS17 data, we strongly believe we are looking at sand injectites in the Eocene strata. These differ from the more typical mud diapirs seen within Eocene units in the central part of the Møre Basin. Gas is normally involved when we get diapirs like this. Possible trigger mechanisms for the extensive remobilization and possible sand injectites include rapid loading effects from the progradation of the thick North Sea fan during the Plio-Pleistocene or overpressure due to gas. The mother beds are either Palaeocene (Våle) sands or more likely an Eocene sandy delta sourced from Tampen.

Rose Bank analogue

The southwestern part of the AMS17 3D survey area is named the **Møre Marginal Plateau**, which extends from the UK border north of the Brendan Basin in the southwest to the Jan Mayen lineament in the northeast. The Møre Marginal Plateau is defined by a 150-km long row of structural highs based on gravimetric data. The main reason that these highs remain untested is poor seismic imaging due to the volcanic complex covering them. The volcanic complex consists of brecciated flood basalts and pillow lavas interfingered with normal nearshore sediments. Even if the 3D data is not finished in processing yet we observe rotated fault blocks, tilted and faulted strata defining sub basins around the gravity defined highs. In front of the volcanoclastic delta we have found several Rosebank analogues (intra-basalt oil discovery, West of Shetland) with possible bright and soft Palaeocene sands between basalt layers (see Fig 9).

Within the oil window

The best part of this emerging story is that we model these sub-basalt rotated fault blocks to be within the oil window. Any source rocks present could then fill leads the same way we see in the northern Viking Graben or the Halten Terrace. The question is what the structural highs below the basalts represent. Is it the Upper Jurassic rifting event (the last known rifting phase in this area) or an older phase? In addition, we interpret the fairways of two big Palaeocene fan systems (one is the Tulipan fan) that passed between the highs and should contain courser clastic sediments. Recent advances in a depth-processing test show thick lenses of low-velocity bodies right under the basalts that could correspond to the thick Palaeocene fan complexes.

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The 3D acquisitions

The AM17 project consists of two volumes, AMS17 and AMN17, and totals so far 32,000km2 (45,000 km2 within 2018). The 2017 acquisition went well without any mayor incidents reported with regard of technical downtime, HSE issues or conflicts with the fisheries. TGS utilized five big vessels in 2017 from Polarcus and Shearwater and had record high productivity from medio April to early October 2017. TGS will be back with two vessels from June this year to finish and extend on the project. The large size of the projects ensures effective production with average swat lengths of 120 km. To get even more effective production and at the same time secure high data density, a triple source configuration is used. This gives 50% higher cross-line data density, thus allowing overlapping recorded shots that also gives high in-line sampling. Below 5.3 seconds recording the shot gathers have overlapping energy from the previous shots that needed de-blending in processing.