Prospectivity of the outer mid-Norwegian volcanic rifted margin constrained by new 3D seismic data and links to the Faroe-Shetland Basin

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The northeast Atlantic volcanic rifted margin covers a vast offshore area spanning the continental shelves of the UK, Norway and the Faroe Islands, along with the conjugate east Greenland margin. A wide diversity of discoveries have been made along the margin ranging from fractured Lewisian basement to Eocene sandstone fan reservoirs. A number of areas along the margin including in the Faroe Shetland Basin and the Halten and Dønna terraces have had significant exploration success encountering a range of plays sourced dominantly from regionally prolific Jurassic source rocks. Exploration in the outer parts of the margin including the deep Cretaceous basins of the mid-Norwegian Møre and Vøring basins has been significantly less to date and form the focus of this contribution. Beyond the shallow platform areas, exploration targets have dominantly been Late Cretaceous to Paleocene with a handful of economic discoveries having been made, notably including the Aasta Hansteen and Ormen Lange fields. Poor reservoir properties and challenges in predicting the distribution of reservoir sands have been key challenges. The Møre Basin has been given the least exploration focus to date and contains vast largely untested prospective areas (Figure 1). A few deep-water exploration wells have been drilled in the Møre Basin, including a gas discovery (Tulipan) in the central Møre Basin hosted within lower Paleocene sandstones jacked up by an underlying saucer shaped igneous intrusion (Figure 2).

In 2017, TGS completed the acquisition of two huge 3D seismic surveys (30,000 km^2 combined), covering large areas of the Møre and southern Vøring basins (Figure 1). These surveys are now revealing unprecedented insights into the geological structure and prospectivity of these frontier regions. We have completed a comprehensive seismic interpretation of the Cenozoic and Cretaceous sequences in the Møre and southern Vøring basins, with a focus on the structural and sedimentological framework and associated igneous complexes. Interpretations are tied to key wells in the Faroe-Shetland Basin and wells on the Norwegian margin. Late Cretaceous to Paleogene aged turbidite sandstones are present in large parts of the Møre and Vøring basins and provide both stratigraphic and structural targets including in association with major Cenozoic inversion structures. Potential reservoir sandstones may be sourced from the NE Greenland and Jan Mayen conjugates in the west or the Norwegian-Shetland mainland to the east. Source rocks are likely Cretaceous shales for the deep basin areas. Seismically imaged gas leakage pipes, shallow gas hydrates and free gas below the gas hydrate stability zone, indicate the presence of an active petroleum system (Figure 3). Exciting new imaging of high amplitude glacial channels and interpreted sand intrusions, with clear similarities to discoveries in the northern North Sea, also add to the exploration potential within the region.

Regional seismic mapping reveals a distinct shallowing of the Base Cretaceous Unconformity (BCU) towards the marginal highs with potential Jurassic and/or older sedimentary sequences being imaged along with a number of major structural closures within the reach of exploration boreholes.

Thermal modelling along a transect through the Møre Basin based on this regional mapping also points to the potential for Jurassic source rocks in the oil window in the outer Møre Basin. [1] The marginal highs remain untested offshore mid-Norway, however, Jurassic sequences are proven in the Lochnagar sub-basalt discovery beneath the Rosebank field, in a similar setting to the south in the West of Shetland region.[2]

The marginal highs are influenced by early Cenozoic break-up related extrusive and intrusive magmatic rocks which become restricted to sill intrusions and associated hydrothermal vent complexes in the deep basin areas.[3] The extrusive units in particular complicate seismic imaging due to scattering and energy loss associated with the volcanic facies - the so-called sub-basalt imaging problem. However, with the acquisition of new high-quality 3D seismic surveys and the application of igneous seismic geomorphology, new insights into the evolution of volcanic rifted margins and their associated petroleum systems has been enabled.

The influence of these magmatic features on petroleum systems is known to be both positive (e.g. trap formation, enhanced maturation) or negative (e.g. compartmentalization, volcaniclastic sediment input) depending on a range of factors.[4] In both the Tulipan discovery, along with examples from the Faroe Shetland Basin e.g. the Laggan and Tormore fields, the presence of sill intrusions beneath the petroleum accumulations has had little to no observable negative effects on the overlying reservoirs. In both cases, however, the presence of the intrusions and associated hydrothermal vents have potentially had positive influences in terms of trap formation and migration pathways respectively.[5,6] Therefore, with good 3D data, careful mapping and appraisal, the presence of even extensive magmatism within prospective basins does not have any a priori negative impact on prospective petroleum systems.

3D data critically enables imaging of features such as channels and detailed amplitude variations (Figure 3) that were hard or impossible to capture previously based on available 2D data. In conclusion, large underexplored areas of the Møre and Vøring basins offer many new exploration opportunities, including Jurassic, Cretaceous, Paleogene, and even Neogene plays.

References

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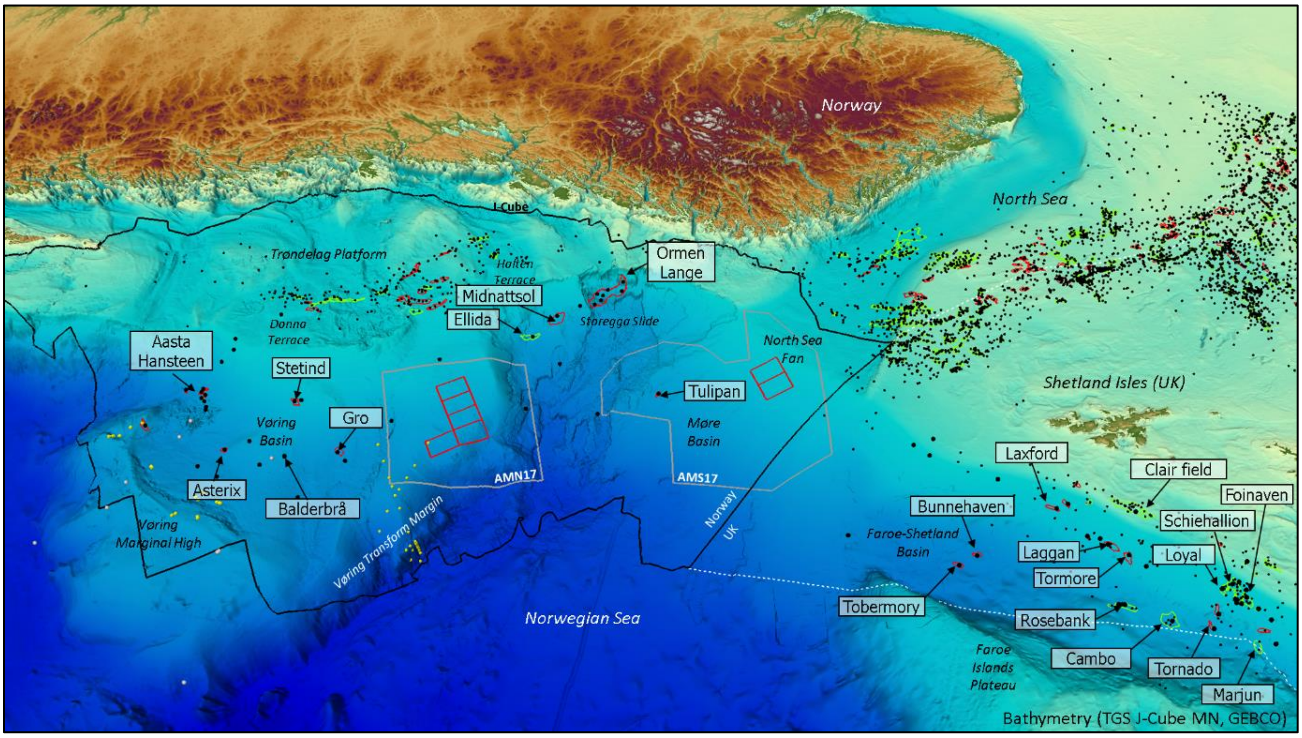

Fig 1. Bathymetry map showing the location of key discoveries in the Møre and Vøring Basins along with the Faroe-Shetland Basin region. Outlines of the new TGS 3D surveys (AMS17 and AMN17) are highlighted.

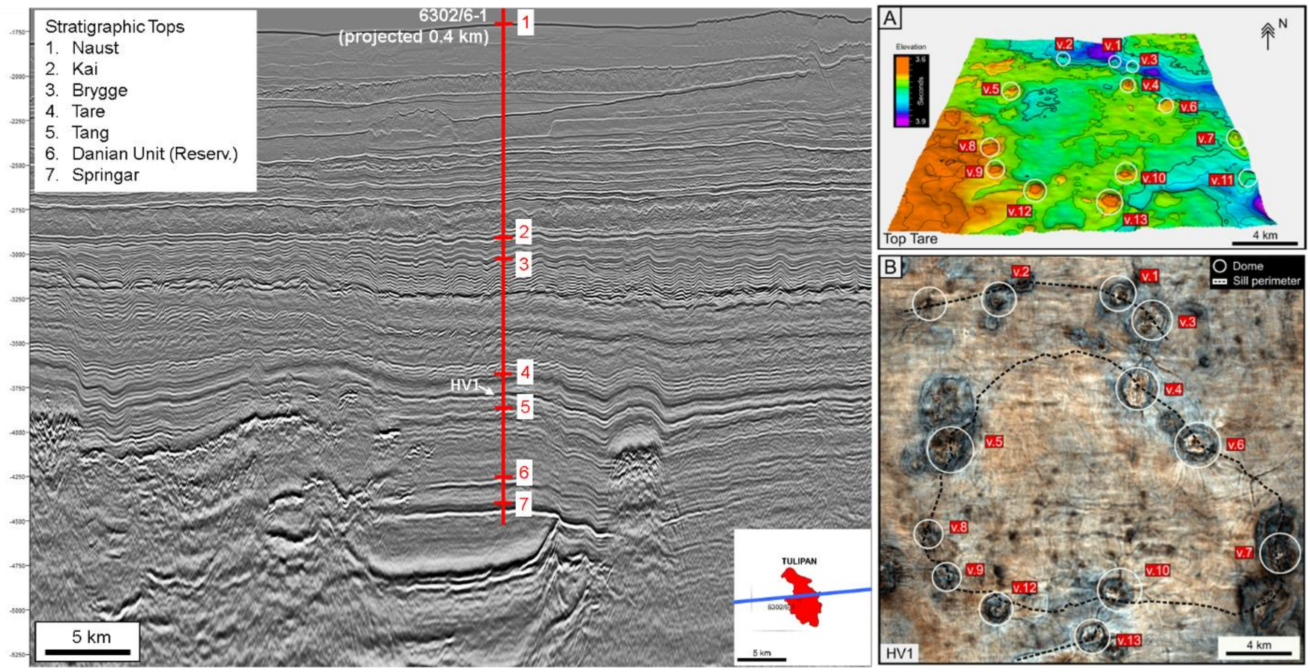

Fig 2. Seismic line showing the Tulipan gas discovery in the central Møre Basin along with a depth and RGB amplitude surface extraction from surfaces above the sill showing the multiple hydrothermal vent structures around the periphery of the underlying saucer shaped intrusion (after Kjoberg et al., 2017).

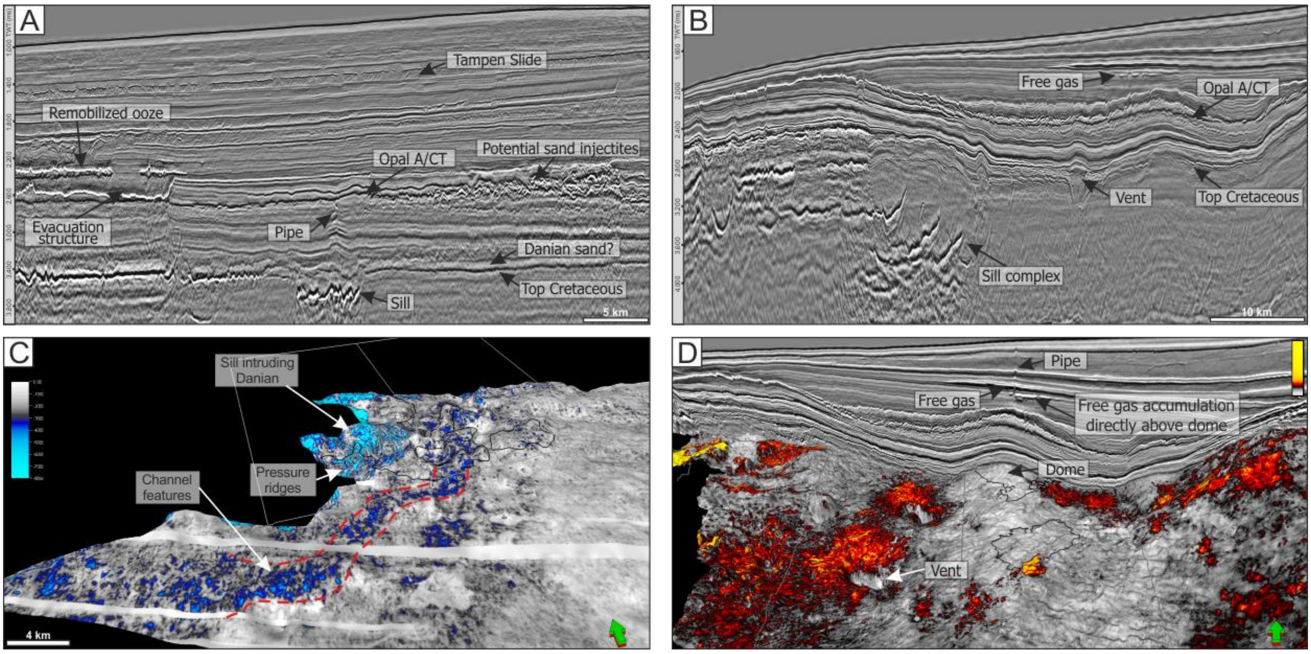

Fig 3. A-B. 2D lines through the AMS17 and AMN17 fast-track data respectively with various features highlighted. C. Minimum amplitude from Top Cretaceous to Top Danian draped on Top Danian from the AMS17 Fast Track 3D data volume, highlighting a potential channel. D. Paleocene RMS amplitude draped on Top Cretaceous from the AMN17 Fast Track 3D data volume highlighting a large dome with evidence for gas migration and free gas beneath the gas hydrate stability zone.