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Inter-Basalt Prospectivity at Elongated Ridges in the NE Atlantic

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Summary

The discovery of the Rosebank oil and gas field in the NE Atlantic has identified inter-basalt reservoirs as significant targets for future exploration. Top and Base Basalt and numerous overlying amplitude anomalies are mapped on 3D seismic data in two study areas: West of Shetland (UK) and the outer Vøring Basin (Norway). We describe seven undrilled elongated ridge structures which are defined at Top Basalt level. Above these ridges are stacked amplitude anomalies interpreted to be caused by hydrocarbon leakage. In the Vøring Basin seabed sampling finds that both oil and gas seeps occur at the seabed above these anomalies. In the West of Shetland area, well data from Tobermory (214/4-1) and Bunnehaven (214/9-1) as well as a seismic well-tie indicates that the basalt sequences at the two wells are diachronous. Seismic interpretation shows that the basalt sequences overlie each other and that a clastic sand-rich unit observed at both wells potentially extends between the basalt units. Four of the basalt ridges occur where the sand-rich unit observed at the two wells could be an inter-basalt reservoir. Overlying amplitude anomalies suggest the reservoir may be charged.

Introduction

Elongated ridges are observed in the NE Atlantic at the Top Basalt level. These ridges are multi-level structural closures with potential inter-basalt reservoirs. Inter-basalt reservoirs are significant targets for future exploration after the successful discovery of the Rosebank oil and gas field, West of Shetland. Inter-basalt reservoirs consist of non-basalt units, such as clastic sandstones, inter-bedded within basalt sequences, such as lava flows. Identifying inter-basalt reservoirs is often challenging due to seismic imaging difficulties caused by the basalt sequences which are highly reflective and cause scattering of seismic waves.

Stacked seismic amplitude anomalies are commonly localized above the elongated ridges. Stacked seismic amplitude anomalies can be interpreted to be caused by the upward migration of hydrocarbons if they have geometries not constrained by depositional or other geological features. The locations of the stacked amplitude anomalies directly above closures suggest that hydrocarbons are trapped within the closures and hydrocarbons are migrating upwards from the underlying accumulations. Seabed sampling analyses may document that hydrocarbons are seeping from such traps.

Data and Methods

Multiple seismic volumes have been interpreted in the NE Atlantic (Fig. 1). Horizons are mapped using seismic data supported by gravity, magnetic and well data. Amplitude anomalies are mapped using root-mean-square (RMS) amplitude extractions. Top Basalt is interpreted as a strong hard reflection (caused by an increase in acoustic impedance). Base Basalt is interpreted as a soft reflection, which occurs above distinct saucer-shaped reflections which are interpreted to be igneous sills and is associated with deeper seismic attenuation. In the West of Shetland study area, 16 horizons have been interpreted at 11 stratigraphic levels using primarily data from two seismic cubes, the westernmost of which was recently acquired and is at the fast-track stage of processing. In the Vøring Basin, 12 horizons have been interpreted regionally of which three (Top Basalt, Base Basalt and Top Naust) have been mapped locally within a seismic volume in the outer Vøring Basin (Fig. 1). Amplitude anomalies in the seismic data are compared to seven seabed sampling sites in the outer Vøring Basin acquired in 2016. Sediment cores were analysed for seeps using two geochemical and one microbiological method.

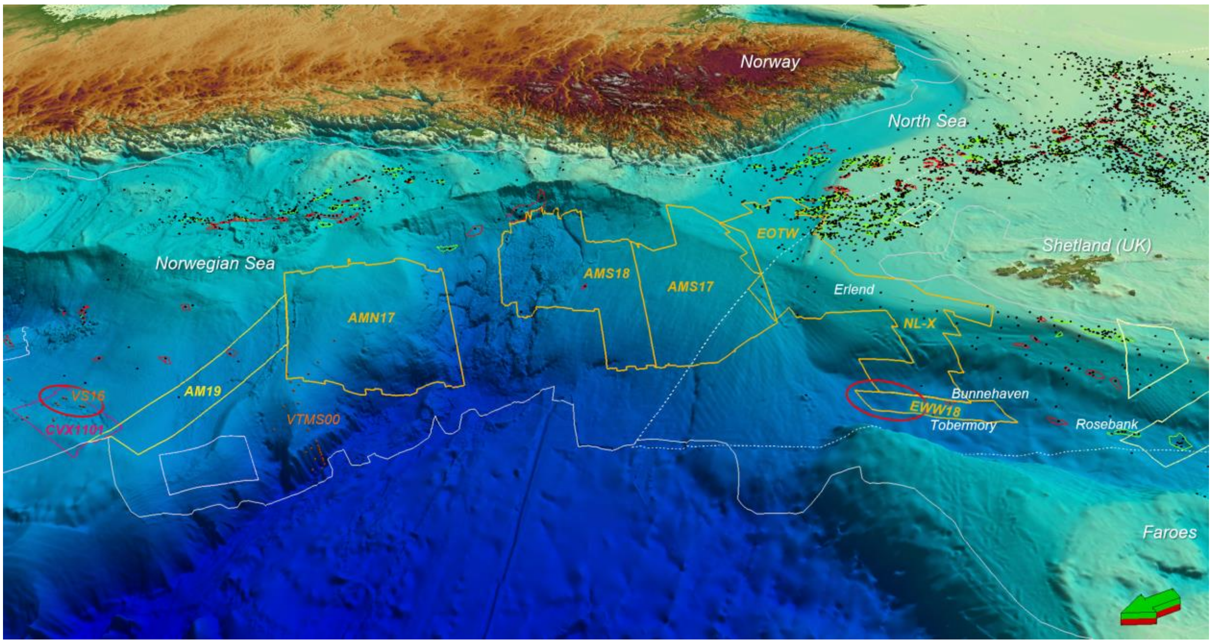

Figure 1 *Bathymetry and data coverage. The two main study areas are outlined with red ellipses. Seismic surveys used in the project are outlined. Wells (black), discoveries (red and green) and sampling sites (orange) are shown. Bathymetry data is interpreted from regional seismic data and GEBCO data.*

Results

The map of the Top Basalt horizon reveals numerous elongated ridges (Fig. 2). The ridges occur where the top basalt surface is rough (Fig. 2) and the internal seismic facies of the basalt sequences are highly disrupted (Figs. 3 and 4). These features are characteristic of the inner flows domain which occurs landward of the basalt escarpments. The ridges are not associated with basalt thickness changes and occur in an orientation approximately parallel to the oceanic spreading axis. These factors suggest the ridges formed due to compression post-emplacement of the basalts. Five elongated ridge structures are identified where the basalts occur, of these, four have not been drilled (Fig. 2, ridges A-D), which at their structural spill points have together a total closure area of c. 35 km^2 (Fig. 2). The origin of the compressional deformation is somewhat uncertain, however, it is commonly attributed to Cenozoic inversion which affects many areas along the continental margin, although the fold wavelengths are much smaller than many inversion folds (such as the Helland-Hansen Arch).

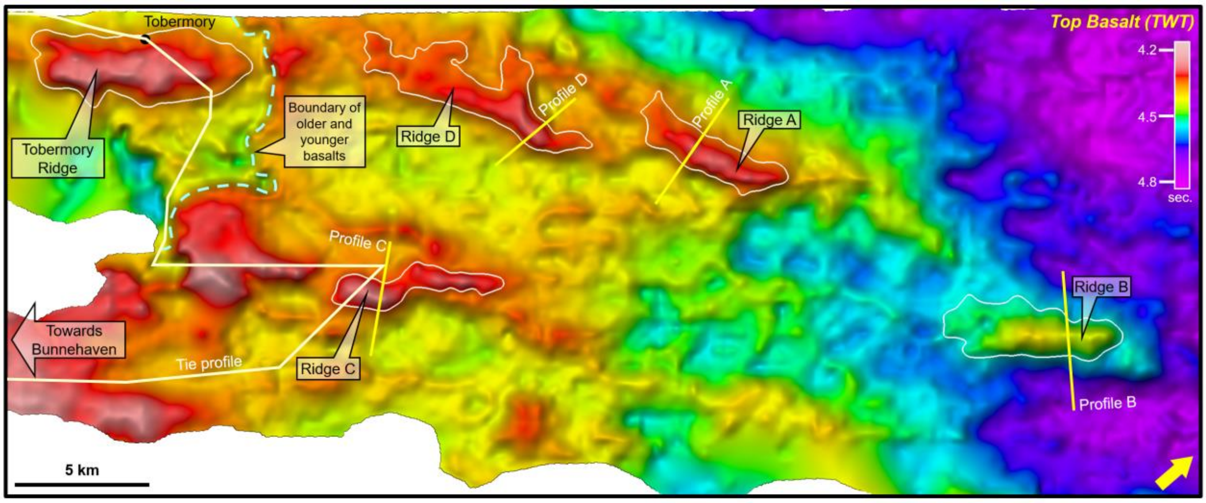

Figure 2 *Top Basalt mapped in West of Shetland. Elongated ridges are labelled. Ridges A-D have not been drilled. Unlike at the Tobermory Ridge, the other four ridges occur where two basalt units are interpreted to overlie each other, there could be an inter-basalt sand-rich unit where these ridges occur. At the Tobermory Ridge the sand-rich unit occurs above the basalt. The well-tie profile is shown in Fig. 3 and profiles A-D are shown in Fig. 4. Data courtesy of TGS.*

Tobermory (214/4-1) and Bunnehaven (214/9-1) are two wells in the northern Faroe-Shetland Basin which intersect basalt (Fig. 1). At Tobermory there is a Flett Formation sand-rich unit which is c. 250 m thick and occurs above the older basalts, while at Bunnehaven (219/9-1) it occurs predominantly below the younger basalts (Fig. 3). The sand-rich unit is c. 95 m thick below the basalts and c. 20 m thick above the basalts. The basalt unit is c. 20 m thick. The sand-rich unit is likely deposited from the east as suggested by metamorphic-index heavy mineral associations which are reported in the 214/4-1 final well report (UK NDR). At Bunnehaven there is a gas discovery within the two sand-rich units.

The well-tie profile between Tobermory (214/4-1) and Bunnehaven (214/9-1) demonstrates that the basalt sequences are diachronous between the two wells and that there are areas where the two basalt sequences overlie each other (Fig. 3). Where the basalt sequences overlie each other, it appears that the sand-rich unit observed both at Tobermory and Bunnehaven continues between the basalt units indicating the sand-rich unit was deposited during a hiatus in magmatism during the latest Paleocene to earliest Eocene. This sand-rich unit could potentially continue as an inter-basalt reservoir to where the ridges A-D occur (Fig. 2).

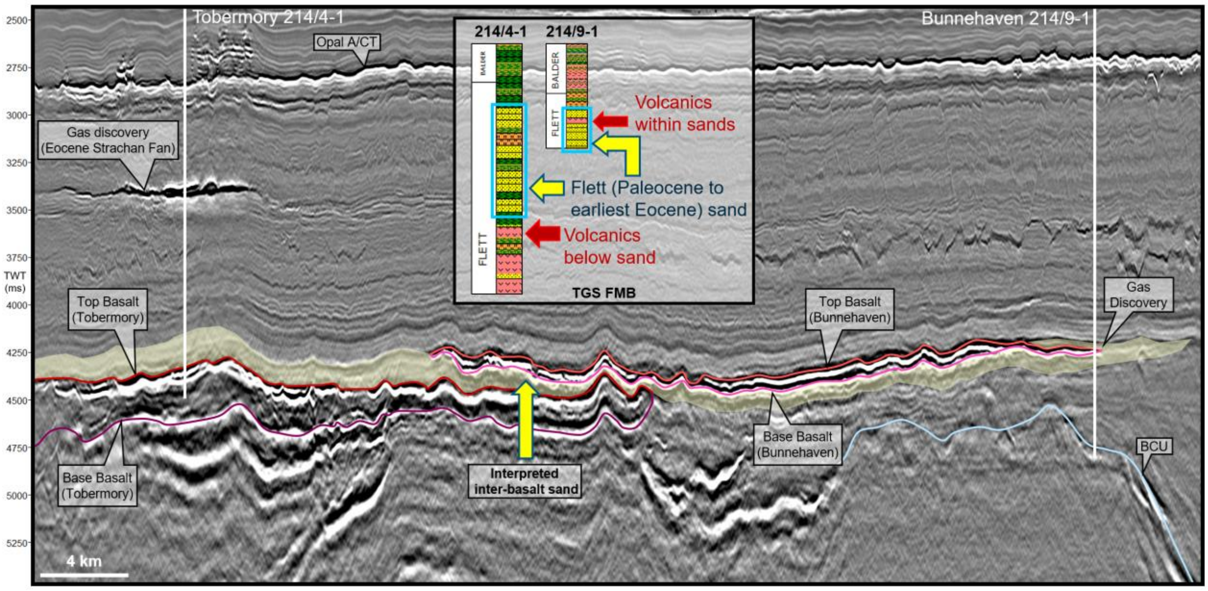

__Figure 3__ Well-tie between the Tobermory and Bunnehaven wells. The line has a complex geometry so as to show both basalt units and where they overlap. The profile location is shown in Fig. 2. The inset shows part of the lithology descriptions from the well data. The profile illustrates that Top Basalt and Base Basalt are different between wells. The sand-rich unit is interpreted based on the well data and seismic data and shaded in yellow. In the centre of the profile (northern area) the sand-rich unit is interpreted to occur between the two basalt units. The Base Cretaceous Unconformity (BCU) is relatively shallow at Bunnehaven. Seismic and well data courtesy of TGS.

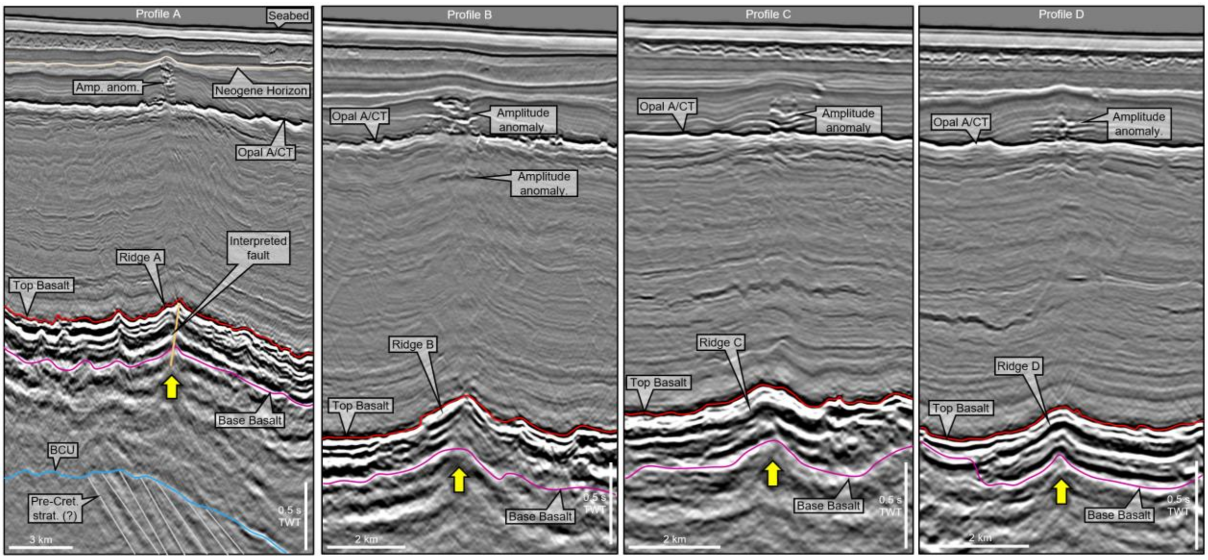

__Figure 4__ Four untested elongated ridges within West of Shetland. Each of the ridges form four-way closures. The inter-basalt and sub-basalt reflectivity is poorer than above. Above all four ridges are stacked amplitude anomalies which occur above the Opal A/CT diagenetic transition. These anomalies are interpreted to be caused by hydrocarbons. Data courtesy of TGS.

Above the elongated ridges are stacked amplitude anomalies (Fig. 4). They occur above the Opal A/CT diagenetic transition and below a distinctive soft reflection within the Neogene. The amplitude anomalies occur directly above the crests of ridges and do not have geometries reminiscent of sedimentary features, therefore, they are interpreted to be caused by hydrocarbons migrating from the crests of the ridge structures below. Well data and the low reflectivity of the sedimentary succession above the elongated ridges indicates it is mudstone dominated without good reservoirs, except perhaps just above the basalt unit (like at Bunnehaven). Therefore, the amplitude anomalies suggest that it is likely the hydrocarbons are migrating from the ridges i.e. from sub- or inter-basalt reservoirs. The ridges may have sub-seismic fractures which enable some upward migration of hydrocarbons.

Amplitude anomalies below the Opal A/CT horizon only occur locally as small anomalies (such as in profile B). The lack of anomalies below the Opal A/CT horizon may be the result of an increase in porosity above the Opal A/CT, which may enable the hydrocarbons to be more visible in the seismic data. The anomalies stop at the Neogene horizon suggesting they are sealed predominantly by the shallowest units.

Elongated ridges are also observed in the outer Vøring Basin (Fig. 5) which also have prominent overlying amplitude anomalies. In this case the amplitude anomalies appear in the seismic data to stop at the Base Naust reflection (Top Neogene). Seabed sampling finds oil and gas seeps to be associated with some of the amplitude anomalies and ridges. This supports the interpretation that the amplitude anomalies are caused by hydrocarbons migrating from deeper accumulations. The reservoir unit is less well known here due to a lack of near wells, nonetheless the reservoir is unlikely to be much shallower than the ridges because in the Vøring Basin this is not known as a reservoir interval nor is there evidence in the seismic data for a shallow reservoir (like there is at Tobermory for instance – Fig. 3). This suggests the reservoir is close, within or below the basalts.

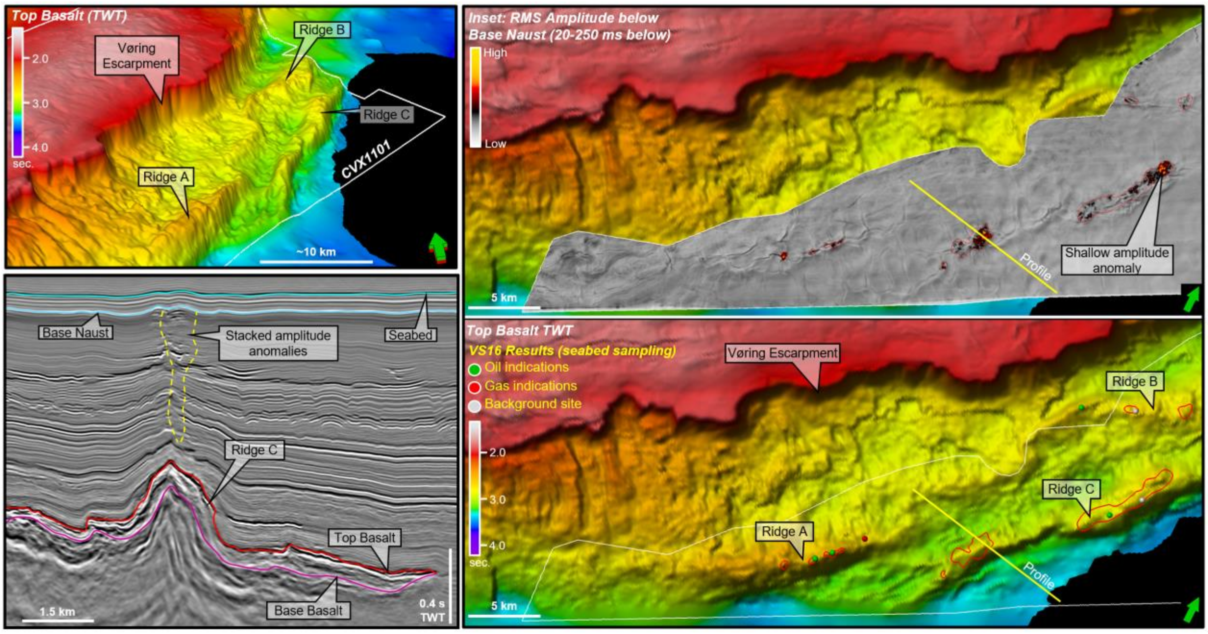

Figure 5 *Elongated ridges within data from the Vøring Margin. The top left image shows Top Basalt using 3D and 2D data. The ridges occur east of escarpment. Bottom left shows a seismic profile highlighting a ridge and associated amplitude anomaly. Poor imaging occurs below the basalts. Top right shows an RMS amplitude extraction from Base Naust, showing where shallow amplitude anomalies occur. Bottom right shows the relationship between sampled hydrocarbon seeps, amplitude anomalies (outlined in red) and the underlying ridges. Sampling results courtesy of VBPR and TGS.*

Conclusions

Elongated ridges occurring landward of basalt escarpments form clear multi-level structural closures. The presence of seismic amplitude anomalies above these ridges supports the possibility that hydrocarbons may have accumulated in sub- or inter-basalt reservoirs. In West of Shetland, well data from Tobermory (214/4-1) and Bunnehaven (214/9-1) as well as seismic data suggests that an inter-basalt clastic reservoir may be present within four elongated ridges. These elongated ridges are novel exploration targets in the inter-basalt and sub-basalt domain which have relatively thin basalts.

Acknowledgements

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