Introduction

The Northern parts of the Barents Shelf are significantly uplifted and reservoirs thus presently occur at very shallow depths (< 1 km beneath the seafloor). In addition, many of the structures are highly compartmentalised and segmented, affecting the lateral integrity of the sealing rock units. This study aims to examine how the seals vary laterally, how they have been influenced by the uplift and exhumation in the area, and why some prospects result in discoveries, while others fail. The Northern Barents Sea is still considered a frontier exploration province. The data are scattered, and the seismic coverage is limited compared to the more explored Southwestern areas of the shelf (e.g. Hammerfest Basin).

The Barents Shelf has so far produced a number of discoveries, but only two fields are currently in production (Snøhvit, gas and Goliat, oil). The area has undergone a complex geological evolution, deep burial and subsequent exhumation. The uplift is estimated to vary from 1000 – 3000m (Gabrielsen and Kløvjan 1997, Henriksen et al. 2011b, Ktenas et al. 2017), depending on various techniques used, but the common findings show that it is the Northern parts of the Barents Shelf that has undergone the highest amount of uplift (Ktenas, et al. 2017). The Svalbard archipelago represents the maximum uplift of the shelf. Understanding the timing and magnitude of exhumation is critical for characterizing both sealing units and source rocks, with deep burial also contributing to degrading reservoir properties through diagenesis. The Barents Shelf is, with unfortunately few exceptions, primarily a gas province and the gas expansion during uplift is significant. Furthermore, uplift typically reduces top seal integrity through for instance decompaction fracturing, and hydrocarbons may leak out of traps. Seismic interpretation from 2D lines in the Hoop Fault Complex (HFC) (Fig. 1) indicate that some of the fault may cut through the URU (Upper Regional Unconformity, an easily recognizable seismic reflector in the Barents Sea) but this is not verified yet, and will be studied further using 3D high-resolution seismic. Fault that penetrate the URU may cause some concerns regarding possible fluid migration pathways, and potential failure of pre-existing fractures during fluid injection into the reservoir (which is often necessary to keep the pressure high enough in shallow reservoirs).

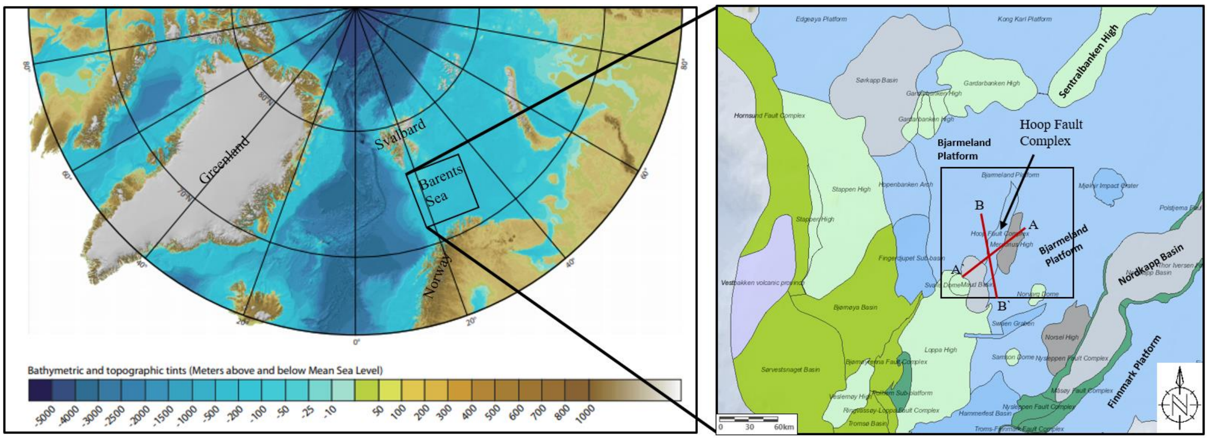

Figure 1 *Overview of the Norwegian Barents Sea, and a close-up of the study area bathymetrical map modified from Jakobsson et al. (2012), Close-up map modified from NPD Fact Maps (NPD 2019). Red lines indicate the position of seismic profiles shown in Fig. 3.*

Data and methods

The integrated databased used in this study includes 2D and 3D reflection seismic from the DISKOS database, available well reports, well-logs and various in-house data provided by the industry. A total of 45 exploration wells and 51 different seismic surveys are incorporated into the project (Fig. 2). Analysing fault systems from seismic data is important for investigating possible leakage from traps caused by the net erosion of the Barents Shelf. Pressure data from wells will aid in the development of local- and regional-scale cap-rock distribution maps, as well as sequence-stratigraphic models.

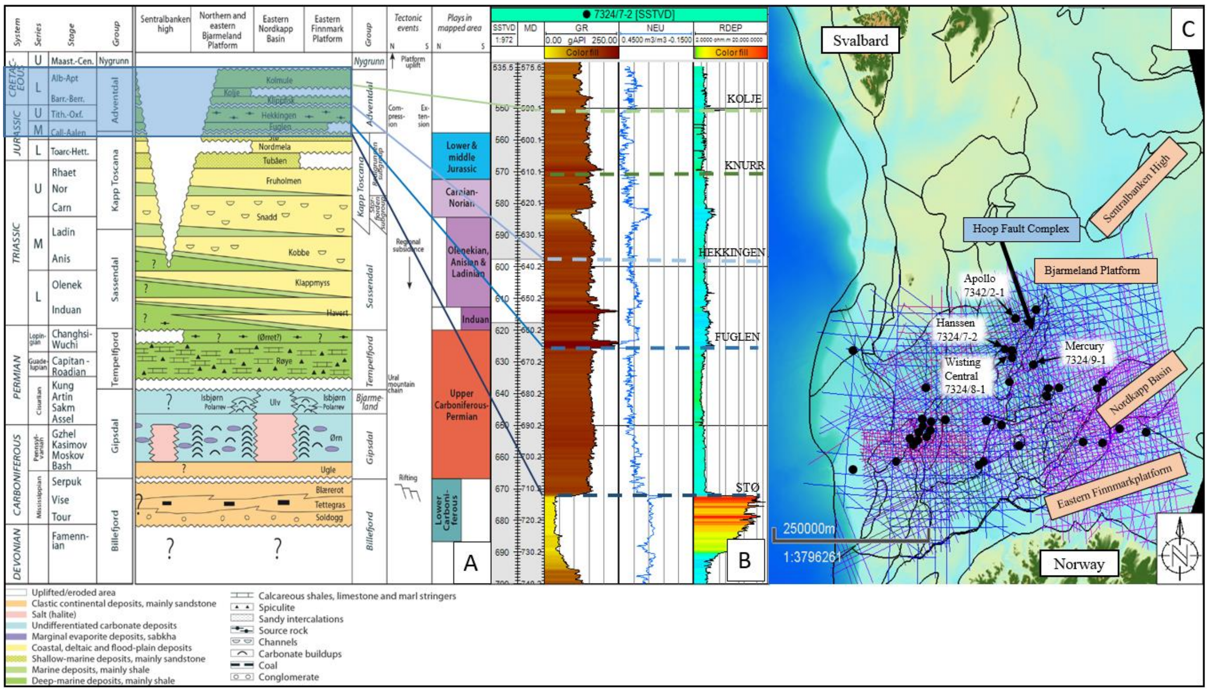

Figure 2 *A: The Jurassic Petroleum system marked in blue alongside depositional environment and erosional surfaces in the Barents Sea. B: Wireline log for well 7324/7-2 (Hanssen) showing the gamma ray response for the top seal and source rock (Fuglen and Hekkingen formations) from mid- late Jurassic. Stratigraphic chart is obtained and modified from NPD (2017) C: Some of the seismic lines interpreted, as well as location of wells (black dots) with black outline of the basin configuration as marked in Fig 1.*

Geological history of the Northern Barents Shelf

The evolution of the Barents Shelf is generally governed by large scale tectonic events, from the Caledonian orogeny in early Devonian, multiple Paleozoic and Mesozoic rifting episodes and eventually the continental break-up in the Cenozoic leading to the present-day geological setting (Smelror et al. 2009). The Cenozoic uplift were caused by differential uplift in the Mid. Cenozoic and later by isostatic rebound following extensive submarine glacial erosion during recurrent glaciations (Løseth et al. 1993). The HFC has been active in several periods from the Carboniferous and possibly to the Cenozoic (Gabrielsen et al. 1990) and parallels several larger fault systems consisting of the Bjørnøyrennea, Ringvassøy-Loppa and the Leirdjupet Fault complexes.

Preliminary results

The Wisting discovery (well 7324/8-1) is located adjacent to the HFC (Fig 3.), on the Bjarmeland Platform north-east of the Maud Basin and adjacent to the Mercurius High. The main target in the area is the Middle – Upper Jurassic Realgrunnen Subgroup. The Stø Formation consists of high quality reservoir sandstones, overlain by the shale-dominated Fuglen and Hekkingen formations. The Fuglen Formation is regarded as a viable regional seal and the Hekkingen Formation is the main source rock in the area. The targeted reservoir in Wisting lies only 250m below seabed (-700ms TWT), and is considered ultra-shallow (Stueland 2016). The reservoir is highly compartmentalized, the cap-rocks are highly faulted, and the strata are tectonically tilted. The shallow location of the reservoir indicates recent migration from a deeper seated source, possibly from the adjacent Maud Basin where it is more likely that the Hekkingen Formation is mature.
Roughly 45 km north of well 7324/8-1, the Apollo prospect (well 7324/2-1) was drilled into a similar structural setting, but turned out water-wet (Figs. 2 and 3). Also here the target was the Realgrunnen Subgroup, and the Stø Formation showed excellent reservoir quality. Seismic interpretation shows

highly spaced faults, and a consistently shallow source rock, with a slight deepening to the SE, cut by a deeper seated fault ca. 25 km SE of the well trajectory. The lithology of the Fuglen Formation is relatively consistent throughout the area, but the well logs indicates increasing silt contents in the lowers part of the unit northwards along the HFC, implying a possible northwards shallowing of the depositional environments.

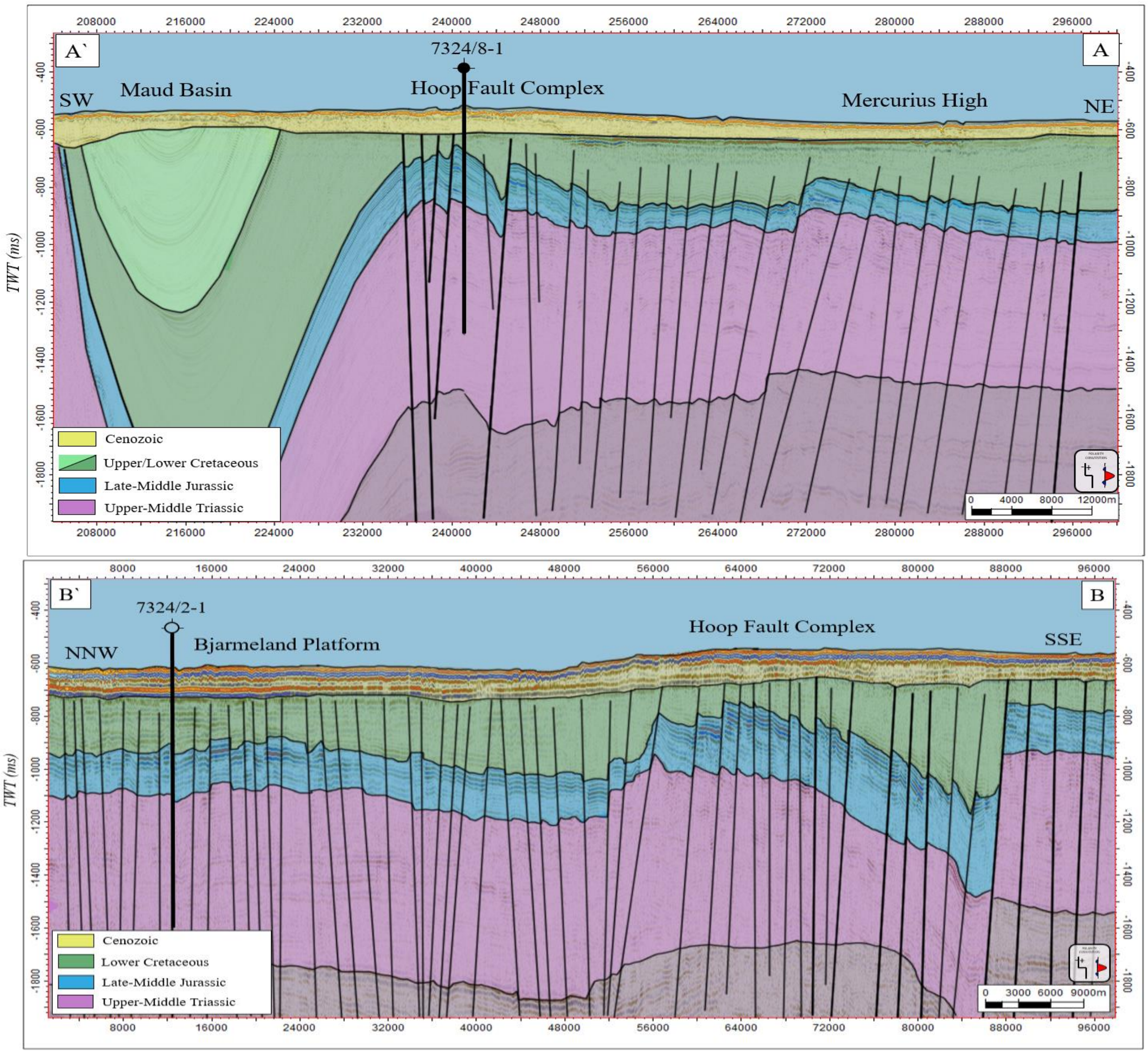

Figure 3 *Generalized and simplified geo-seismic profiles of Wisting (above) and Apollo (below). The 7324//8-1 was drilled ca. 1 km west of the HFC at the east rim of the Maud basin. The 7324/2-1 well was drilled 24 km west of the HFC on the Bjarmeland Platform. Both areas are recognized by closely spaced (simplified) planar faults, bisecting the Jurassic and down into the Triassic strata. From the 2D lines it is not verified or recognized that any of the faults cut the URU, although it should not be ruled out that this may be possible.*

Discussion and outlook

Cap rock integrity problems is a well-known exploration risk on the Northern Barents Shelf. The Wisting discovery is unique in regard to its ultra-shallow location and in spite of the regional cap rock issues. Previous studies of the Hekkingen Formation (Makurat et al. 1992), has shown that the removal of an overburden of 1600 – 1700m, may have caused fracturing and build-up of deviatoric stresses. This means that there is less risk for leakage from cap-rocks in areas characterized by lower rats of uplift. While the Wisting discovery may be charged from a mature source rock in the Maud Basin, such charge is not recognized for the Apollo prospect. Lithology variations within the lower Fuglen Formation locally result in a more brittle response to deformation compared to the more shale dominated upper parts of the formation. The key features for understanding the seal integrity in the HFC will revolve around fault reactivation, and the fault response during injection. Collanega et al. (2017) studied the orthorhombic fault system initiated in the Mesozoic in the Hoop area, implying a connection between the Atlantic rifting and the Arctic rifts for the development of the faults in the upper and brittle successions. Additionally he discusses that pre-existing structures in the lower succession prevented further growth of faults by focusing the deformation, and thus shows that the HFC has developed under multiple stress fields early in the rift phases. Glørstad-Clark et al. (2010) found that the sediment thickness increase in the HFC changed from plane-parallel to clinoform, which would indicating a fault controlled sedimentation across the HFC and that this could have reactivated basement-involved faults due to sediment loading.

High resolution shallow seismic data can aid in the understanding of shallow polygonal faults as migration pathways, and it is important to evaluate the regional thickness of the cap rocks in the area. Additionally the fault orientation and tectonic history, including maximum horizontal stress, may add important information about fault leakage in the area.

Acknowledgments

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