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Gas hydrate systems in petroleum provinces of the SW-Barents Sea

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ABSTRACT

3D seismic data of the SW-Barents Sea provided information about the existence of Structure II gas hydrates and shallow gas in marine sediments. Gas hydrates and shallow gas exist in the SW-Barents Sea in conjunction with deep-hydrocarbon reservoir leakage. Available conventional 3D seismic data show acoustic chimneys that extend to depths ~1700 ms two-way travel time below the seafloor. The location of the chimneys coincides with structural boundaries and fault complexes cutting through mostly Jurassic and Triassic strata. Vertical fluid flow through these chimneys transports thermogenic gas to the gas hydrate stability zone, causing the formation of a bottom-simulating reflector (BSR). In addition, variations of fluid flux across deep-seated fault complexes cause changes in heat flow, which explains the shoaling of the BSR and the formation of a “tilted” BSR (TBSR) at the border between the Ringvassøya Fault complex and the Loppa High. The stability model using thermogenic gas composition (type I and II) shows gas hydrates are stable at ~225 m–~345 m depth, corresponding to variation in the geothermal gradient for upper BSR (28.7 °C/km and 37 °C/km) and lower BSR levels (23.4 °C/km and 28.3 °C/km). These lateral changes in the temperature gradient can be reconciled with changes in upward fluid flow rates of 1.8–2.2 mm yr^{-1}. Such gas-hydrate and fluid flow systems on Arctic continental margins especially in shallow water depths are potential gas emitters due to their sensitivity to warming ocean temperatures.

1. Introduction

Active gas seepages and fluid-escape structures have been reported from continental shelf areas worldwide (e.g. Solheim and ElverhøI, 1985; Hovland and Judd, 1988; Kelley et al., 1994; Rise et al., 1999; Judd and Hovland, 2007; Chand et al., 2008, 2012). The areas of active seepage are associated with sub-seafloor oil and gas reservoirs, trapped gas under gas hydrates, and also dissociation of gas-hydrate itself (Sassen et al., 1999; Milkov and Sassen, 2003). Fluid and gas anomalies that exist in the SW-Barents Sea are particularly concentrated at the border between the Ringvassøya Fault Complex, the Loppa High and the Hammerfest basin (Fig. 1) (e.g. Chand et al., 2012; Vadakkepuliyambatta et al., 2013). Shallow gas and gas-hydrate accumulations in the Barents Sea are poorly understood with respect to their geological control, sediment architecture, seal integrity and leakage conditions. However, deep hydrocarbon reservoirs exist in less explored Triassic and Palaeozoic successions (Henriksen et al., 2011).

Recent findings in the Arctic indicate that the rapid methane degassing of Siberian Arctic shelves and slopes may have already begun (Shakhova et al., 2010), triggered by rapid warming at nearly twice the rate as the rest of the World (IPCC, 2007). Therefore, a better understanding of gas-hydrate distributions and their current stability is necessary to develop better models, which allow us to predict where and under which circumstances significant amounts of methane may reach the ocean and atmosphere in the near future (Mienert, 2012).

Gas hydrates occur worldwide within both active and passive continental margins but particularly favorable conditions exist in Arctic margins and permafrost regions where the pressure and temperature conditions allow for methane hydrate to be stable (e.g. Max, 2000). However, more unstable conditions may exist under rising Arctic Ocean temperatures (Biastoch et al., 2011; Ferré et al., 2012). Gas hydrates in continental margin sediments are inferred from the widespread occurrence of an anomalous seismic reflector in marine seismic reflection records that coincides with the predicted gas hydrate/free gas transition boundary at the base of the gas hydrate stability zone (BGHSZ) (e.g. Shipley, 1979). This reflector is commonly called a bottom-simulating reflector (BSR) because it often runs parallel to the topography of the seafloor (e.g. Shipley, 1979; Bünz and Mienert, 2004).

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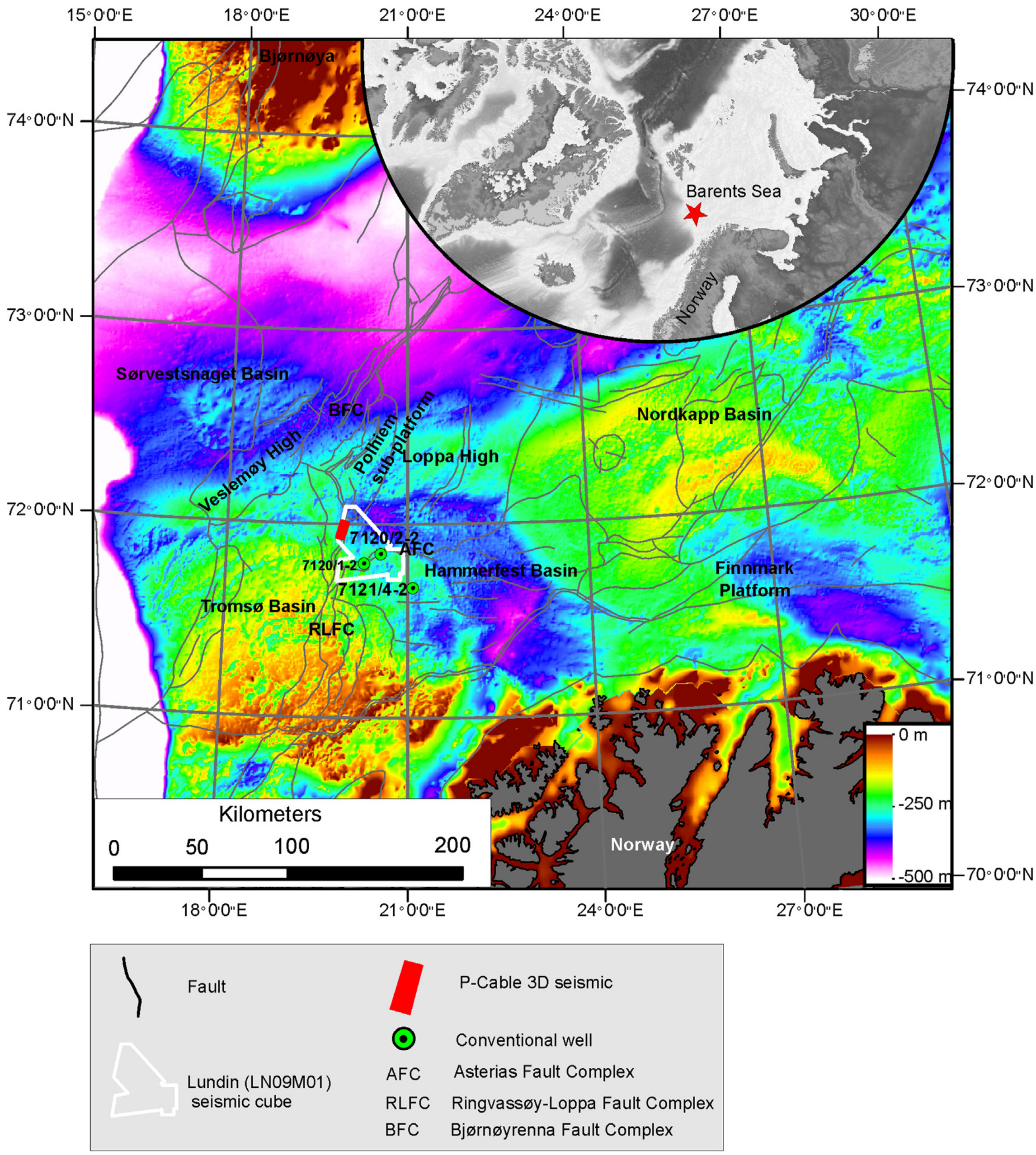

Figure 1. Shaded relief map of the SW-Barents Sea showing with the main structural elements within the study area. Location of 3D cubes that are used in this study is shown.

We acquired high-resolution P-Cable 3D reflection seismic data (Petersen et al., 2010) along the border between the Ringvassøya Fault Complex and the Loppa High in the SW-Barents Sea in ~300–350 m water depths (Fig. 1). Additionally, this study used conventional 3D seismic data that covers a much larger area in this part of the SW-Barents Sea. Potential sources of methane to stimulate gas-hydrate growth in permeable sediments include deeper hydrocarbon reservoirs from which thermogenic gas may leak (Chand et al., 2008, 2012). Gas hydrates and shallow gas reservoirs may connect to deep thermogenic gas leakage sites, which are potentially important for our understanding of natural methane storage and release systems in the Arctic Ocean and shallow Barents Sea. They are also important for providing windows to deep hydrocarbon reservoirs. As a consequence of the potential connectivity, the overall objective of this study is to determine fluid migration pathways from deep hydrocarbon reservoirs to sites of shallow gas and gas-hydrate accumulation, allowing a better understanding of the controls leading to the accumulation of shallow gas and gas hydrate.

2. Geological setting

The Barents Sea is an ~300 m deep marginal sea bounded by the northern Norwegian and Russian coast lines in the south, Novaya Zemlya in the west, Franz Josef Land and Svalbard archipelagos in the north. Toward the east, the shallow Barents Sea connects to the on average ~2000 m deep Norwegian-Greenland Sea. The Barents Sea sub-seabed consists of complex geological platform highs and basin lows (Fig. 1) originally formed during major continental collisions. The first collision event was the Caledonian orogeny, ~400 Ma while the second event was the Uralian orogeny ~240 Ma (Doré, 1995). Tectonic extension started