P-Cable High-Resolution 3D Seismic Imaging of Hydrate Occurrences Over Unusually Large Gas Chimneys in the SW Barents Sea

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The Barents Sea is a large hydrocarbon-prone basin in the Norwegian Arctic region (Fig. 1). In the SW Barents Sea, a significant volume of hydrocarbons is thought to have leaked or migrated upward from deeper portions of the basin into the shallow subsurface, where it is now trapped in gas hydrate and free gas reservoirs (Laberg et al., 1996; Chand et al., 2012). The widespread distribution of these shallow hydrocarbon accumulations was not previously recognized. In addition, the complex nature of these deposits and their mechanism of formation were not known. An extensive seismic mapping project was carried out at the University of Tromsø to better understand the nature and distribution of these shallow gas accumulations and associated fluid flow features in the SW Barents Sea.

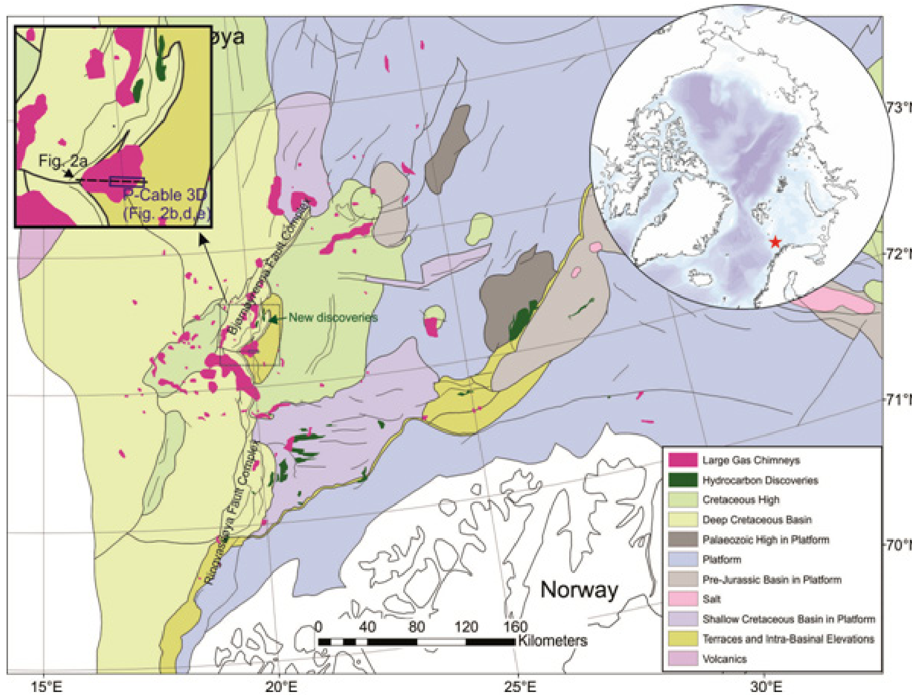

Figure 1. Structural map of the SW Barents Sea with mapped giant gas chimneys indicated in bright pink color. The giant chimneys occur mostly along N-S trending fault complexes and adjacent basins and platforms. The small inset figure shows the location of the seismic examples in Fig. 2.

The interpretation of more than 3000 2D seismic lines in the SW Barents Sea revealed the presence of various subsurface fluid flow features, amongst which gas chimneys are the most common. These gas chimneys originate mainly in Triassic and Permian successions and have typical diameters of a few hundred meters. However, the dense seismic coverage used in this project allowed the identification of a total of 93 exceptionally large gas chimneys, varying from 1 to 600 km^2 in area and displaying

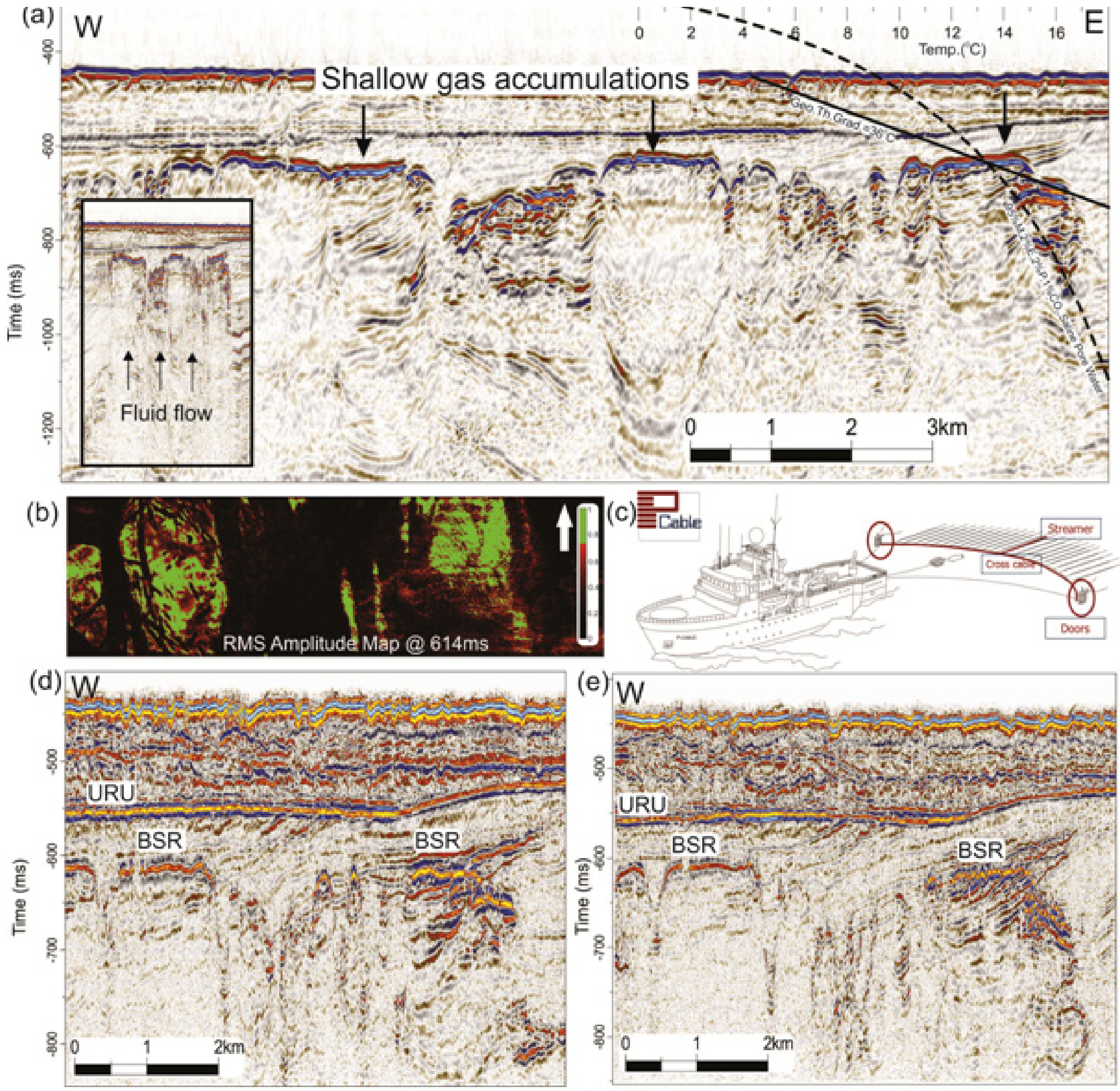

Figure 2. (a) 2D multi-channel seismic profile across one of the exceptionally large gas chimneys showing high-amplitude anomalies interpreted as shallow gas accumulations at the upper termination of the chimney. The small inset figures show that these chimneys extend to great depth and connect with Triassic and Permian sedimentary strata. (b) Root mean square (RMS) amplitude map derived from the high-resolution 3D seismic data at a depth of 614 ms two-way-travel-time that coincides with the predicted base of hydrate stability. (c) Sketch of the P-Cable high-resolution 3D seismic system. (d,e) Seismic examples from the high-resolution 3D seismic data clearly showing that amplitude anomalies cross-cut sedimentary strata and document the presence of a bottom simulating reflector (BSR) indicating the presence of gas hydrates within sediments above giant gas chimneys.

peculiar areal shapes (Figs. 1 and 2a). These gas chimneys occur mostly along major structural boundaries, in particular along the large fault complexes that stretch from south to north in this part of the basin (Fig. 1). This suggests a close relationship to the structural development of the Barents Sea. It is likely that fault reactivation and glaciotectonics during Late Cenozoic time have led to the depletion of deep-seated hydrocarbon reservoirs and upward migration of hydrocarbon gases through gas chimneys (Henriksen et al., 2011).

We also observe reversed-polarity, high-amplitude anomalies in shallow stratigraphic horizons, suggesting the presence of free gas and gas hydrates (Fig. 1). The observed amplitude anomalies occur mainly in Tertiary sediments below a prominent reflection, the upper regional unconformity (URU) a widespread erosional surface separating glaciogenic from pre-glacial sediments. It is likely that hydrocarbon gases that migrated upward are being trapped in these shallow stratigraphic formations.

In order to better understand the complex nature of the shallow gas accumulations, the University of Tromsø, in cooperation with P-Cable 3D Seismic AS and Lundin Norge AS, who funded parts of the cruise, acquired high-resolution 3D seismic data using the P-Cable system (Fig. 2c; Planke et al.; 2010; Pedersen et al., 2010). The P-Cable system is a high-resolution 3D seismic imaging tool. It consists of a cable towed perpendicular to the ship's steaming direction and a cross-cable that is spread behind the vessel by two large trawl doors. Up to 20 multi-channel streamers with a length of 25 m and a separation of 12.5 m are attached to the cross-cable. The streamer array acquires 20 seismic lines simultaneously, thus covering an approximately 200 m-wide swath with close in-line spacing in a cost efficient way. GPS antennas are mounted on both the gun float and the trawl doors to ensure accurate navigation, with uncertainties of less than 1 meter. The spatial resolution of such a system is at least one order of magnitude higher than conventional 3D seismic, whereas the temporal resolution is improved 3-5 times using high-frequency airgun systems. The increase in image resolution facilitates better target identification and allows for more accurate imaging of shallow subsurface structures.

The high-resolution 3D seismic data clearly revealed for the first time that the high-amplitude anomalies that terminate the giant chimneys cross-cut the up-dipping Tertiary sedimentary strata in various parts and mimic the seafloor (Figs. 2d and 2e). This is typical of a Bottom Simulating Reflector, or BSR. The occurrence of a BSR at this depth indicates the presence of gas hydrates in the pore spaces of these shallow sediments. Bottom water temperatures and geothermal gradient information in the area were used to assess the stability conditions for gas hydrate in the region. These predictions match very well with the observed sub-bottom depth of the BSR assuming a gas composition that contains a small amount of high-order hydrocarbons (Chand et al., 2008). Further studies of BSR occurrences and hydrate stability show a highly variable BSR depth in the SW Barents Sea that might be controlled by structural elements and fluid flow through the giant chimneys. Spatial analysis of the distribution of high amplitudes at the top of the chimneys shows a very peculiar shape (Fig. 2b). Further analysis of the high-resolution 3D seismic data is necessary to better understand these complexities and the mechanisms controlling the distribution of the gas hydrate and free gas accumulations.

One may expect that large quantities of hydrocarbons have been released from deep-seated reservoirs in this region. A high flux of gas-rich fluids through the chimneys could have led to significant accumulations of gas hydrates and free gas as recently demonstrated on the Hydrate Ridge, offshore the western coast of the U.S. (Hornbach et al., 2012). Given that the total area covered by the giant chimneys is approximately 3000 km^2, these concentrated occurrences might contain substantial gas hydrate resources. In addition, these gas hydrate and free gas accumulations may pose a hazard to hydrocarbon exploration and exploitation in an area of future development, where two significant oil discoveries have been made during the last two years (Fig. 1). Therefore, it is important to better understand these accumulations and the potential effects of climate change in this environmentally sensitive part of the Arctic region. Future work will focus on the quantification of fluid flow and hydrate resources occurring above the giant gas chimneys.

References

Chand, S., Mienert, J., Andreassen, K., Knies, J., Plassen, L., and Fotland, B., 2008, Gas hydrate stability zone modelling in areas of salt tectonics and pockmarks of the Barents Sea suggests an active hydrocarbon venting system: Marine and Petroleum Geology, v. 25, no. 7, p. 625-636.

Chand, S., Thorsnes, T., Rise, L., Brunstad, H., Stoddart, D., Bøe, R., Lågstad, P., and Svolsbru, T., 2012, Multiple episodes of fluid flow in the SW Barents Sea (Loppa High) evidenced by gas flares, pockmarks and gas hydrate accumulation: Earth and Planetary Science Letters, v. 331–332, no. 0, p. 305-314.

Henriksen, E., Bjørnseth, H.M., Hals, T.K., Heide, T., Kiryukhina, T., Kløvjan, O.S., Larssen, G.B., Ryseth, A.E., Rønning, K., Sollid, K., and Stoupakova, A., 2011, Uplift and erosion of the greater Barents Sea: impact on prospectivity and petroleum systems: Geological Society, London, Memoirs 35, p. 271-281.

Hornbach, M. J., Bangs, N. L., and Berndt, C., 2012, Detecting hydrate and fluid flow from bottom simulating reflector depth anomalies: Geology, v. 40, no. 3, p. 227-230.

Laberg, J. S., and Andreassen, K., 1996, Gas hydrate and free gas indications within the Cenozoic succession of the Bjornoya Basin, western Barents Sea: Marine and Petroleum Geology, v. 13, no. 8, p. 921-940.

Petersen, C. J., Bünz, S., Hustoft, S., Mienert, J., and Klaeschen, D., 2010, High-resolution P-Cable 3D seismic imaging of gas chimney structures in gas hydrated sediments of an Arctic sediment drift: Marine and Petroleum Geology, v. 27, no. 9, p. 1981-1994.

Planke, S., Eriksen, O.K., Mienert, J., Bünz, S., Berndt, C., Lie, J.E., Eriksen. F.N., 2010, P-cable High Resolution Seismic Imaging of Shallow Gas in the Barents Sea, 72nd EAGE Conference & Exhibition, Barcelona, Spain, 14 - 17 June 2010, extended abstract, 5 p.