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GAS HYDRATES AT THE STOREGGA SLIDE ON THE MID-NORWEGIAN MARGIN

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Gas hydrates contain more carbon than does any other global reservoir and are abundant on continental margins worldwide. These two facts make gas hydrates important as a possible future energy resource, in submarine landsliding and in global climate change. Particularly on the mid-Norwegian margin, the recognition of inferred gas hydrate occurrence in close proximity to one of the world's largest submarine landslides has stimulated renewed interest in the role of gas hydrates in slope stability and their potential environmental impact through the release of large quantities of methane into the ocean and atmosphere. Therefore, it is necessary (1) to understand the distribution of the gas hydrates, (2) to assess the amount of gas hydrates and free gas that are stored in the reservoir, and (3) to investigate the key mechanisms that occur in this gas hydrate province, e.g. gas migration and accumulation, hydrate formation and the role of the subsurface geological structure and stratigraphy.

Geophysical evidence for gas hydrates exists along the northern sidewall of the Storegga Slide. A bottom-simulating reflector (BSR) reflects the base of the gas hydrate stability zone (GHSZ) at about 280 mbsf, and covers an area of approximately 4000 km², outside but also inside the slide area (Figure 1). Seismic profile NH9651-202 (Figure 2) shows the typical expression of the BSR in the study area. The BSR generally marks the upward termination of enhanced reflections. The amplitude of the enhanced reflections varies considerably along seismic lines in the study area. The distribution of the gas hydrates shows three major geological controls: (1) the gas hydrate stability conditions that exclude gas hydrates on the continental shelf, because bottom-water temperatures are too high, (2) impermeable glacigenic debris flows that define the northern boundary and inhibit upward migration of fluids into the GHSZ, and (3) the intersection of the base of the gas-hydrate stability with the base of the Naust formation, because sediments of the underlying Kai formation are not conducive for gas hydrate growth. As a result of the geological controls the BSR only occurs within the contouritic and hemipelagic deposits of the Naust formation, which seem to be the favorable host sediments for the gas hydrates.

A detailed analysis of the gas hydrate /free gas system using ocean-bottom seismometer (OBS) and ocean-bottom cable (OBC) data allows us to assess the elastic properties of hydrated and gassy sediments and to image the heterogeneous distribution of free gas and gas hydrate beneath the seabed. Above the BSR, P-wave velocities that are higher than expected unveil the presence of gas hydrates within the sediments at the northern flank of the Storegga Slide (Figure 2). Underneath the BSR, P-wave velocities indicate the existence of free gas. S-wave velocities obtained from the OBS data are unaffected by either the presence of hydrates, or the presence of gas underneath the BSR (Figure 2). In addition, a multi-component OBC line exhibits a BSR only on the P-wave component. No P-S reflections are associated with the BSR along this line, indicating that the gas hydrate-bearing sediments at the base of the hydrate stability zone are not stiff enough to increase the shear modulus of the sediments to produce P-S converted wave reflections. We conclude that gas hydrates do not cement the sediments, but are rather disseminated in the sediment pore space.

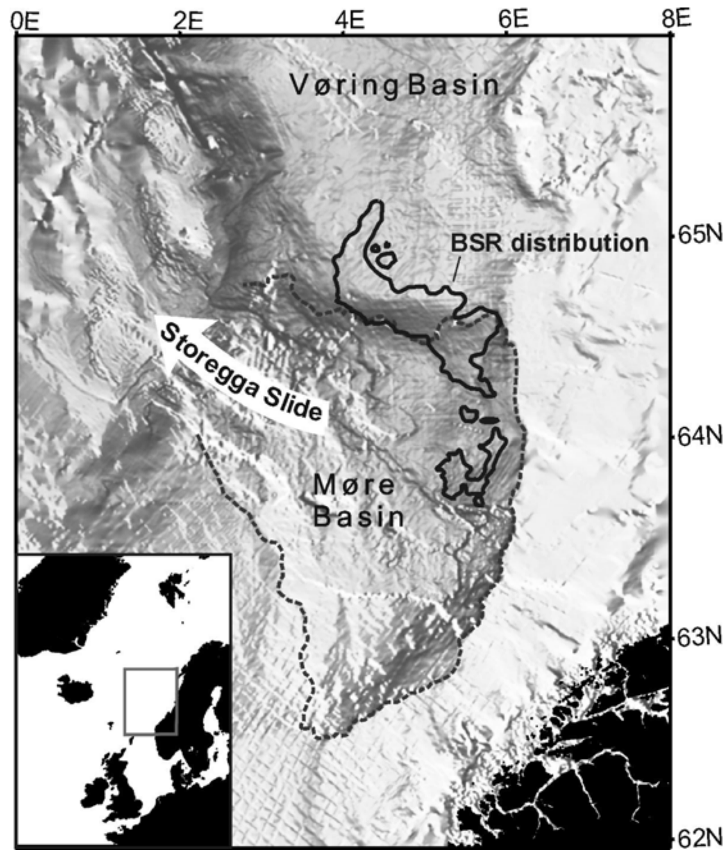

Figure 1: Distribution of a gas-hydrate related BSR (outlined in black) on the mid-Norwegian. The most continuous BSR occurs on the northern flank of the Storegga Slide (black dashed line).S-wave velocities are unaffected by either the presence of hydrates, or the presence of gas underneath the

Gas hydrates occur in an approximately 50-m-thick zone above the BSR and average gas hydrate concentrations are 3 – 6% of the pore space when modeled by weighted-equation theory or effective-medium theory with hydrates as a component of the sediment-frame. Concentrations are up to 6 to 12% when modeled by effective-medium theory assuming hydrates as a component of the pore-fluid. The thickness of the free-gas zone beneath the BSR is about 80 m on average and gas occupies 0.4 – 0.8% of pore volume assuming homogeneous gas distribution or up to 18% of pore volume if the gas is assumed to be patchily distributed.

The heterogeneous distribution of free gas and gas hydrate results from the complex interaction between fluid flow pathways, porosity and permeability contrasts, the location of gas seeps and possibly deep-seated hydrocarbon reservoirs. Gas is predominantly distributed along strata and not along the base of the GHSZ underneath the hydrates. As a result, our data show an increase in gas concentration with depth at certain locations. The gas in the strata significantly increases the impedance contrast causing enhanced reflections on the seismic reflection data. The reflection enhancement terminates at the level of the base of the GHSZ, where hydrates overly and possibly trap gas, causing the BSR to be observed as an envelope of those terminations rather than a distinct reflection. Amplitude anomalies related to the BSR are primarily caused by the gas and not the hydrates.

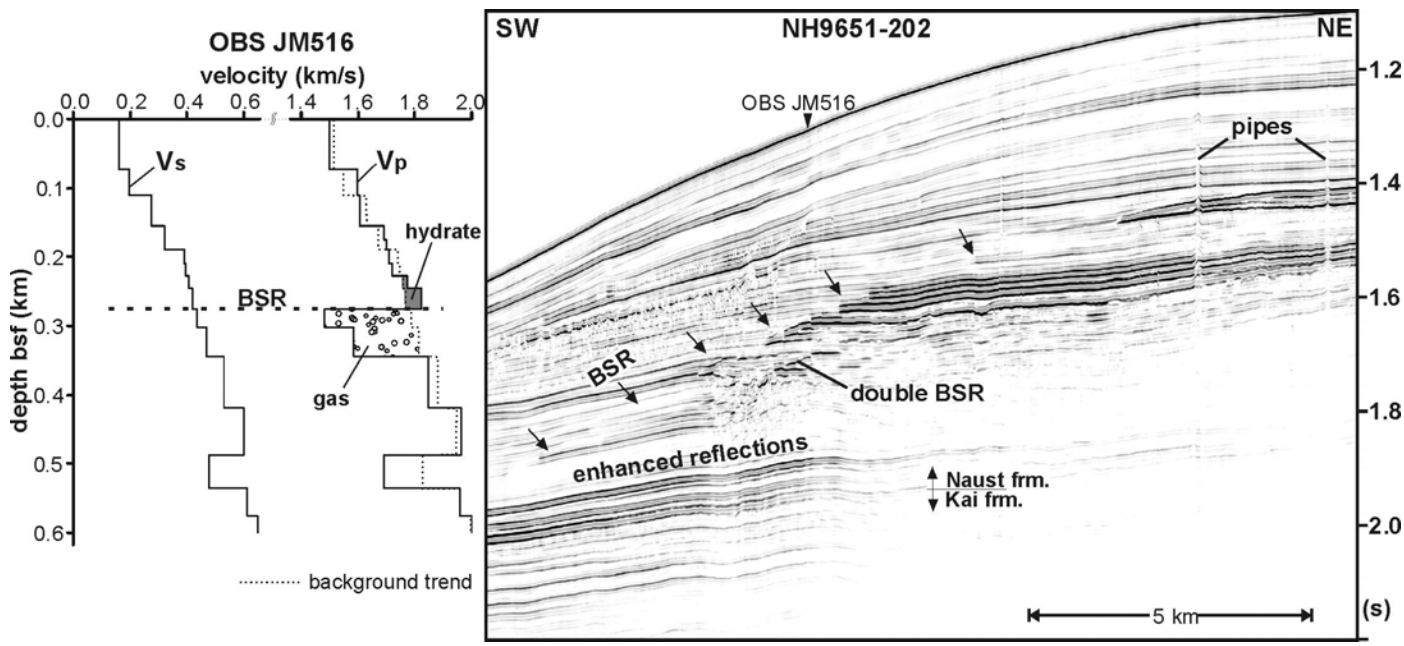

Figure 2: Example of the BSR on the mid-Norwegian margin. The BSR is mainly identified as the termination of enhanced reflections. The P-wave velocity profile of OBS JM516 shows a clear velocity inversion at the depth of the BSR. Higher velocity above the BSR indicates the presence of gas hydrates; lower velocity underneath the BSR provides evidence for the presence of free gas within the sediments. S-wave velocities are unaffected by either the presence of hydrates, or the presence of gas underneath the BSR. Therefore, we conclude that gas hydrates do not cement the sediments, but are rather disseminated in the sediment pore space.

The Storegga gas hydrate system appears to be a very dynamic system due to a polygonal fault system that occurs in the sediments underneath the hydrate-bearing sediments. Development of polygonal faults and the related expulsion of formation water might drive the fluid flow in the area. Gas hydrates seem to concentrate directly above the base of the GHSZ, which indicates that gas hydrates most likely develop from gas-rich fluids that migrate into the GHSZ from sediments below. Deep-seated Tertiary dome structures with inferred hydrocarbon reservoir might be one of the most likely sources of gas. However, the exact origin of gas remains for further investigation.