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Fluid dynamics at the base of hydrate-bearing sediments at the Vestnesa Ridge inferred from 5 years of high-resolution 4D seismic surveying

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Capturing the dynamics of natural fluid flow processes using 4D seismics

The **4D time-lapse seismic method** intend to identify and monitor fluid movement in the subsurface over certain time intervals. Although conventional 4D seismic has a long history of application to monitor fluid changes in petroleum reservoirs, **high-resolution** seismic data (20-300 Hz) as a tool for **4D fluid monitoring of natural geological processes** has been recently identified (Waage et al., 2019).

One of the most active parts of a fluid flow- and gas hydrate system is at the **phase-boundary between stable and unstable hydrates**. Here, small alterations in pressure, temperature, heat flux, gas supply or access to water have potential to alter hydrate stability, leading to hydrate formation and dissociation and associated changes in free gas accumulations. In addition to phase-transition related differences, other processes occurring along the BSR may involve pressure build-up of gas accumulations trapped beneath the hydrate layer which may lead to **fracturing of hydrate-bearing sediments or reopening of existing fractures** - enabeling advection of fluids Into the hydrate layer and potentially seabed seepage. Furthermore, depletion of gas along zones of weakness creates **hydraulic gradients** in the free gas zone where gas is forced to migrate along the lower hydrate boundary towards these weakness zones.

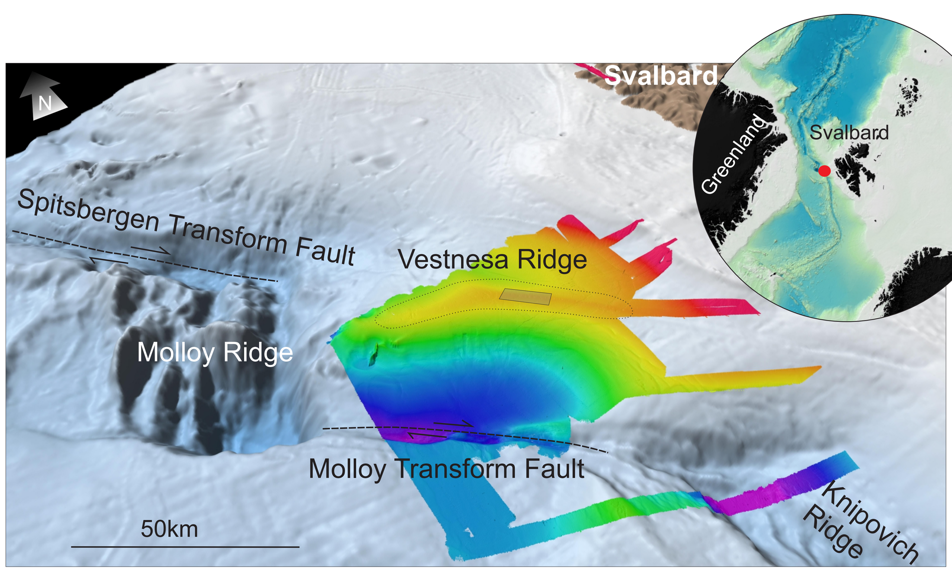
The Vestnesa gas hydrate and seepage site

The Vestnesa Ridge is a a well-known fluid flow and gas hydrate province, situated in 3-4 km thick deep-water (1200-1300 m water depth) contourite drift deposits at the western Svalbard margin.

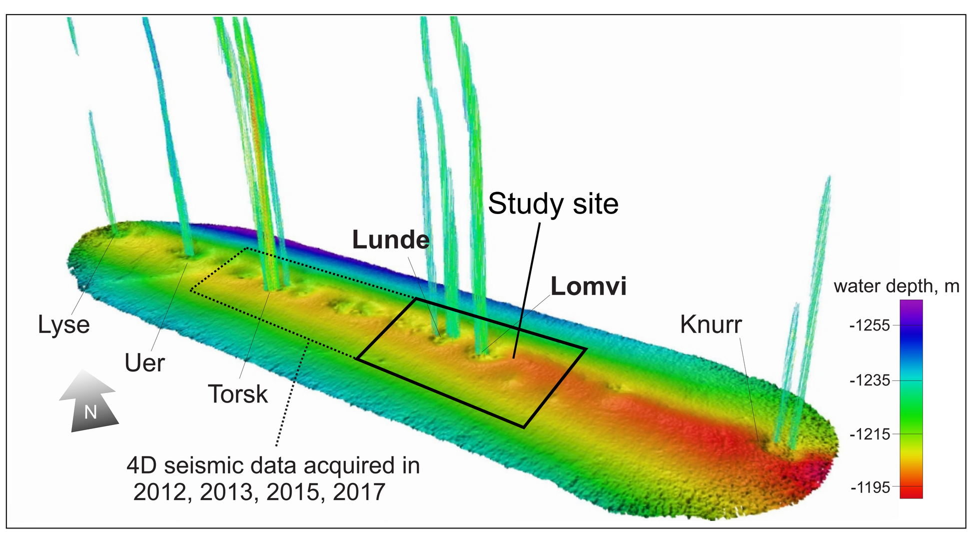
To capture the short-term dynamics of gas hydrate and free gas accumulations, we present 4D seismic data along the hydrate-free gas transition zone in the subsurface of the Lunde- and Lomvi pockmarks - two active seafloor seepage areas.

Using velocity analysis from OBS-data, Singhroha et al., (2019) estimate free gas saturations of 1-4% in the free gas zone beneath the hydrate stability zone in the study area. If only slightly altered, such small gas saturations have the potential to cause large 4D differences (Meckel et al., 2019).

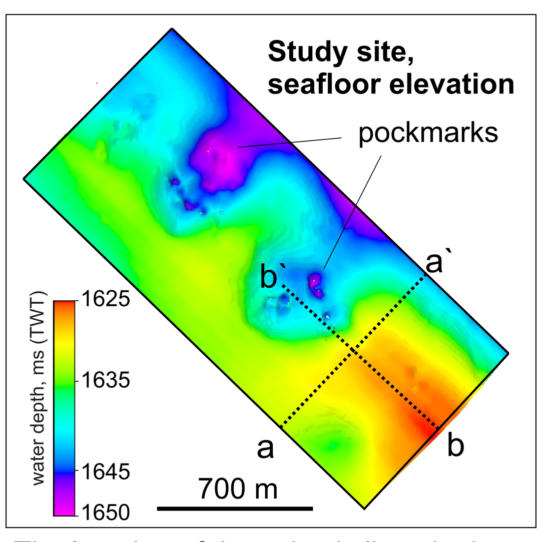
However, "real time" data enables to further investigate the magnitude and timescales of processes at the gas hydrate – gas contact zone



Location of the study site - The Vestnesa Ridge



800 m - tall echosounder signals capturing gas bubbles in the water column.



The location of the seismic lines in the figures below are shown as a-a`and b-b`.

High-resolution P-Cable time-lapse seismic data between 2012 and 2017

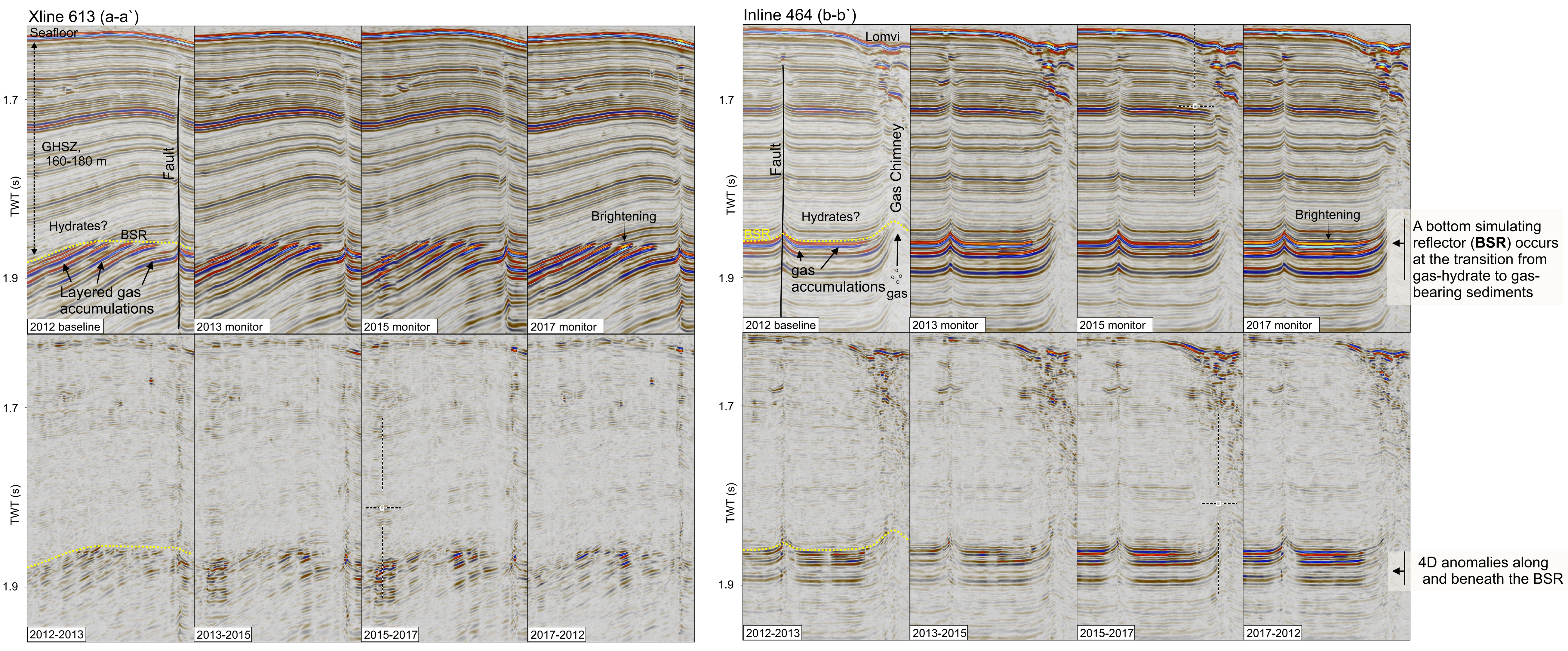


Figure 1. Seismic and difference examples of the 2012, 2013, 2015 and 2017 time-lapse datasets. The data is denoised with an edge-preserving smoothing filter.

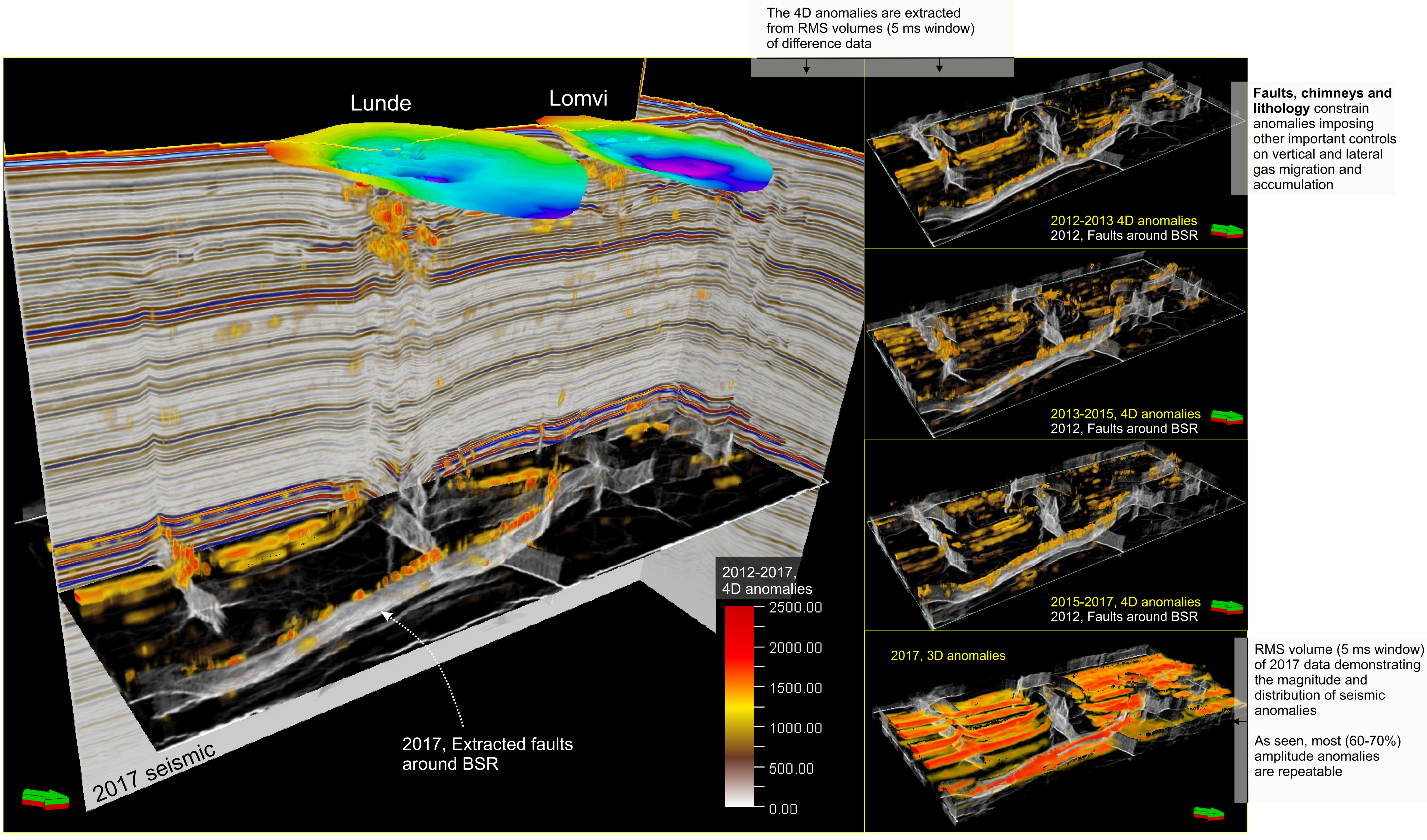


Figure 2. Overview of all 4D anomalies in the study area extracted from RMS amplitude volumes. Although most anomalies are well-repeated, 4D anomalies occur along fracture zones, in chimney areas and along some layers truncating the BSR.

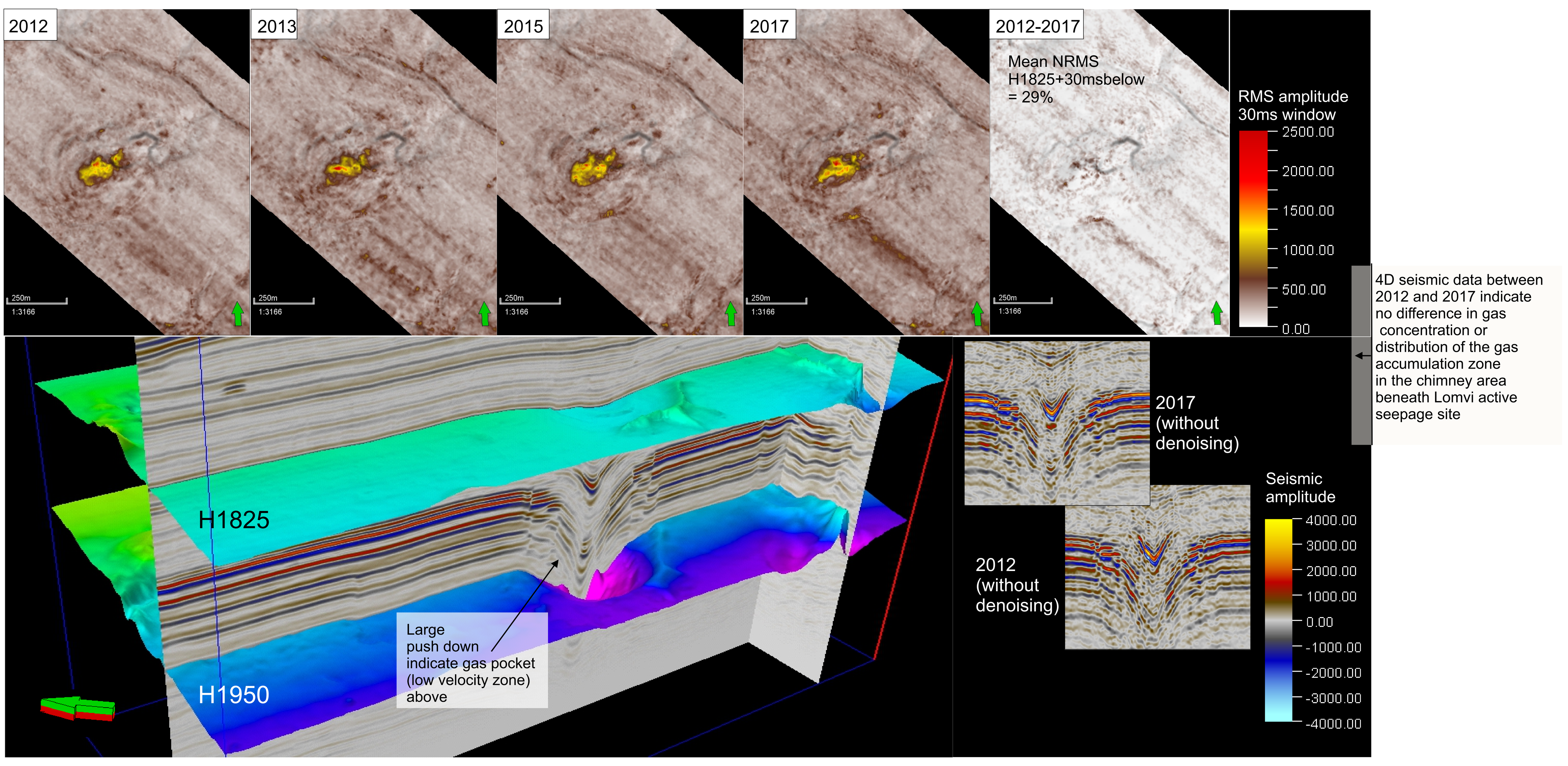


Figure 3. Gas pocket in the chimney beneath the Lomvi seepage area indicate the immediate gas source. As seen, there is absence of 4D anomalies between the 5 years interval between the surveys.

Discussion and preliminary conclusions

- The time-lapse differences and high repeatability along the BSR at the Vestnesa Ridge suggest that (1) we can resolve fluid changes on a year-year timescale in this natural seepage system using high-resolution P-Cable data and (2) that fluids accumulate at and migrate along and up through the base of the hydrate stabiltiy zone over the same time-scale.
- 4D anomalies occur along faults, in chimneys and at some sedimentary layers truncating the BSR. Disappearance of bright reflections suggest that gas-rich fluids have escaped the free gas zone and possibly migrated into the hydrate stability zone and contributed to a gas hydrate accumulation, or alternatively, migrated laterally along the BSR. Appearance of bright reflection might also indicate lateral migration, ongoing microbial or thermogenic gas supply or be related to other phase transitions.
- However, most of the BSR and underlying brights (60-70%) are repeated between the surveys, and there is not a larger difference with larger time-span (not more difference between 2017 and 2012 versus i.e. 2012 and 2013), suggesting relatively small gas-related changes between the time of the surveys.
- Alternatively, the fluid dynamics at the BSR might have a shorter peridiocity than 1-5 years, or in a steady state condition where the inflow equals the outflow at the time between the surveys. This coinsides with the observations that more changes occur at shorter time-differences i.e. 2015 to 2017, than on a longer time-scale (2012-2017) (Figs. 1, 2).

This is an early work, so any concerns/questions or discussions around the preliminary results are very welcome!

References
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