Towards meter-scale resolution of 3D seismic data: theoretical analysis and case studies in the Barents Sea and the Vøring Basin

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High-resolution 3D seismic data are important for hydrocarbon exploration, geotechnical site characterization, and geohazards assessment. Our goal with this presentation is to identify the acquisition parameters required for meter-scale seismic resolution of shallow targets (less than ~600 mbsf) in a continental shelf environment, and then to verify these estimates based on real data. Our theoretical estimates show that seismic signal grater than ~400 Hz can provide meter-scale data resolution and propagate down to ~100-300 mbsf depending on attenuation properties of sub-surface. Therefore, a seismic source with a flat spectrum from ~10 Hz to ~600 Hz, uniform trace density of more than four million traces per square kilometer, and source-receiver offsets of less than ~200 m are sufficient acquisition parameters to achieve meter-scale horizontal and vertical resolution.

We have performed two case studies based on re-processing and analyzes of 3D P-Cable seismic data. The first case study is based on P-Cable data collected by the University of Tromsø in 2013 for monitoring methane hydrate systems and fluid flow phenomena on the Vestnesa Ridge west of Svalbard. The data acquisition configuration permitted a natural bin size of 3.125x6.25 m. Our high-frequency seismic re-processing workflow allowed to image the first tens of meters below the seafloor with one-meter vertical resolution. Deeper structures (down to ~100-200 m) were possible to image with 2-3 m vertical resolution due to the high signal attenuation in the sediments. Data re-processing increased the level of details, including better definition of faults and imaging of chimney structures throughout the upper hundred meters of the sub-surface.

For the second case study, 2.5D P-Cable seismic data from the outer Vøring Basin were re-processed as a 3D swath with a 6.25x6.25 m bin size, focusing on uplifting the high-frequency components. The sediments in this area are characterized by uniform thin layers and low signal attenuation. These sub-surface properties allowed imaging of structures with decimeter- to meter-scale vertical resolution for the upper several hundred meters below the seafloor. The re-processed data show the directions of faults and potential fluid leakage structures within the 90 m-wide swath. Results of a seafloor seep sampling campaign in 2016 revealed oil indications at the fault termination. The re-processed data allowed to better visualize and map a number of potential fluid migration zones that can be targeted in future sampling surveys.

Our studies show that there is no physical limitations, besides signal attenuation properties of the sub-surface, for obtaining meter-scale data resolution. In addition, the case studies show that 3D P-Cable seismic data in combination with geological sampling provide the base for meter-scale 3D site characterization. Overall, re-processing of existing P-Cable 2.5D and 3D data can provide higher resolution images of the shallow subsurface whereas collection of new 3D P-Cable data with optimized acquisition parameters will provide meter-scale horizontal and vertical resolution.