High-resolution core-log-seismic integration and igneous seismic geomorphology of IODP Expedition 396 sites on the mid-Norwegian margin

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Summary

The breakup of the Norwegian-Greenland Sea 56 million years ago was associated with massive basaltic magmatism and a short-lived global warming episode, the Paleocene-Eocene Thermal Maximum (PETM). Scientific drilling in 2021 targeted sediments and volcanic rocks on the mid-Norwegian margin to test hypotheses related to the formation of large igneous provinces as well as global warming associated potentially with the igneous activity. High-resolution 3D site survey data facilitated optimal borehole locations during the drilling; key reflections were targeted using the high-resolution 3D data, and PETM stratigraphic intervals were recognized during shipboard core descriptions. Igneous seismic geomorphological interpretation, furthermore, reveals distinct volcanic morphologies on the marginal high, related to different volcanic emplacement environments.

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Introduction

The P-Cable high-resolution 3D seismic technology was developed in the early 2000's motivated by the need for detailed core-log-seismic integration of scientific boreholes in the deep oceans (e.g., Planke and Berndt, 2007; Planke et al., 2009). The system may provide 3D seismic data with a meter-scale resolution of the uppermost kilometer of sediments (Lebedeva-Ivanova et al., 2018). Over the years, the technology has been used extensively on the Norwegian Continental Shelf for tasks such as mapping shallow gas (e.g., Planke et al., 2010) and high-resolution 3D imaging of petroleum reservoirs (e.g., Garden et al., 2017). The data can also potentially be used to document the presence of CO_2 leakage structures (Waage et al., 2021).

The aim of this paper is to document how high-resolution 3D seismic data can be used for scientific drilling. The International Ocean Discovery Program (IODP) Expedition 396 drilled 21 holes at 10 sites on the outer Vøring and Møre margins in 2021 (Figure 1; Planke et al., 2023). The overarching expedition goals were to test hypotheses related to the formation of voluminous continental breakup volcanism and how such magmatism could be associated with the Paleocene-Eocene Thermal Maximum (PETM). To achieve these goals, both the basaltic basement (6 sites) and Paleogene sediments, including a hydrothermal vent complex (4 sites) were drilled, recovering >2 km of core (Planke et al., 2023).

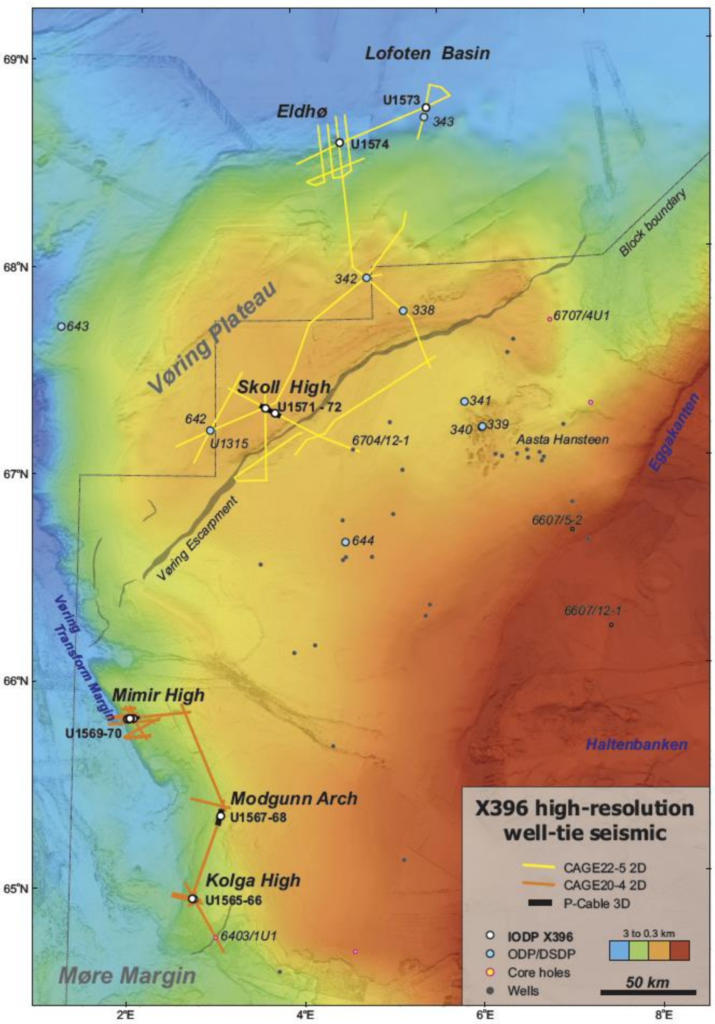

Figure 1 *Bathymetric map of the mid-Norwegian margin showing seismic profiles and drill sites.*

Site Survey Data

Site survey data were acquired in August 2020 and July 2022 by the R/V Helland-Hansen during the two-week long CAGE20-4 and CAGE20-5 cruises (Figure 1; Bünz et al., 2020; 2022). Almost 1500 km of high-resolution 2D profiles, multi-beam echo-sounder bathymetry, and sub-bottom profiler data were acquired. In addition, three P-Cable 3D cubes (21, 9, 8 km^2) and four gravity cores were collected. The 3D data were acquired using a 14-streamer P-Cable system, with 25 m active sections and 12.5 m separation, and two mini GI air guns (30/30 in^3 and 15/15 in^3) with a shot point interval of 6 seconds. Fast-track processing was completed using RadexPro software. All 10 IODP Expedition 396 sites were tied, in addition to four legacy ODP/DSDP sites.

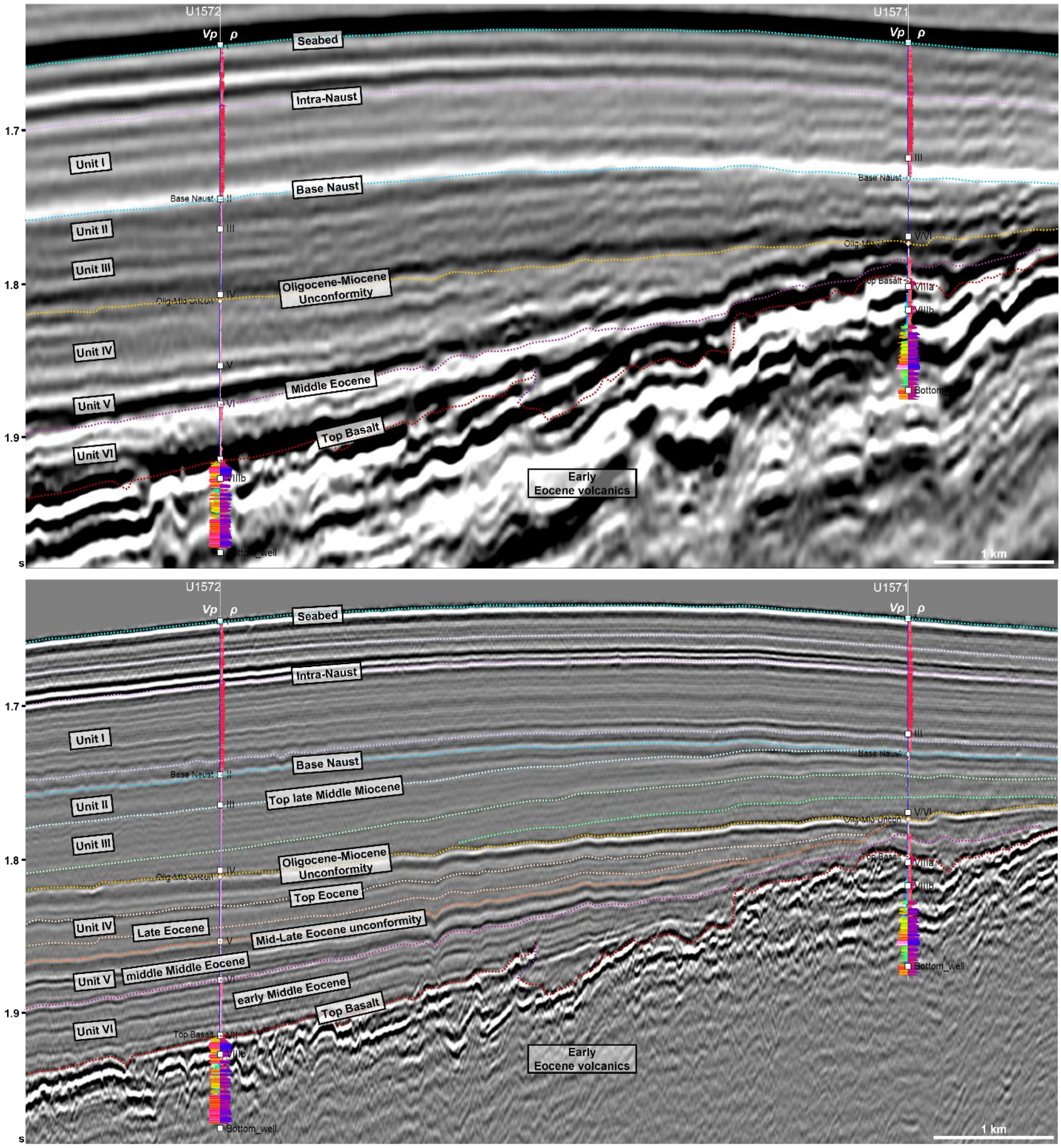

Figure 2 *Comparison of seismic data between IODP wells U1571 and U1572. The upper figure illustrates CVX1101 conventional seismic data and the lower figure illustrates high-resolution CAGE22-5 Skoll3D data.*

Results

Five boreholes were drilled in the Modgunn Vent, targeting the upper part of the vent structure. Two holes, U1567A and U1568A, cored 200 m of sediments, and were subsequently logged (Planke et al., 2023). The high-resolution 3D data were then used to locate three additional holes, to ensure optimal recovery of the vent infill. Shipboard results document that the vent consists of a crater that was subsequently in-filled during the PETM. Five boreholes were drilled on the transform margin high (the Mimir High; U1569-U1570; Planke et al., 2023). Here, the high-resolution 3D seismic data reveal extensive lateral variability in reflection characteristics. Careful offshore assessment of the core and the seismic data allowed for a good recovery of the Paleocene-Eocene transition.

The CAGE22-5 survey aimed to collect P-Cable 3D seismic data across the two sites drilled on the Skoll High (U1571 and U1572; Planke et al., 2023). Igneous seismic geomorphological interpretation of conventional data suggested that the sites are located in two different basalt domains; a pitted domain and a faulted domain (Planke et al., 2017) (Figure 2). Horizon interpretation and attribute analysis of the high-resolution data reveals a crisp definition of the seismic geomorphology of the top basalt surface (Figure 3). We interpret the different geomorphologies to be related to variations in basalt emplacement environments, with the pitted domain being related to basalt flows emplaced in a wetland environment, whereas the landward faulted domain is related to basalt lava flows emplaced subaerially and subsequently faulted.

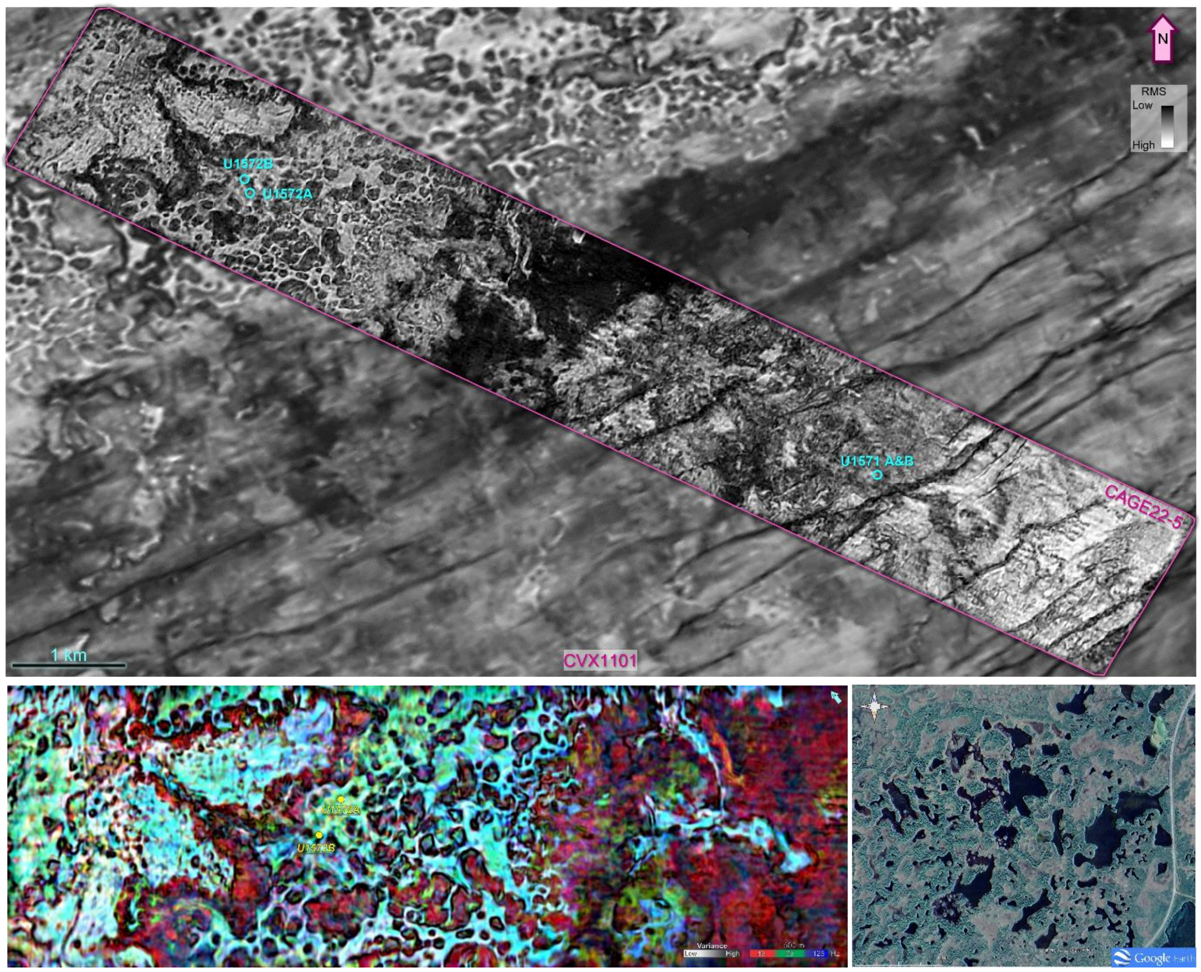

Figure 3 *Top Basalt pitted surface. The top panel shows the RMS amplitude at Top Basalt in the high-resolution CAGE22-5 Skoll3D data (inside purple outline) [25 ms window] and CVX1101 conventional data [35 ms window]. The lower left panel is a spectral decomposition of the Skoll3D*

data flattened at Top Basalt blended with variance. The spectral decomposition was made using the Correlation algorithm, in Petrel software, using three frequencies (45 Hz – red, 85 Hz – green, 125 Hz – blue). The lower right panel shows the western part of the Myvatn lake area, Iceland, from Google Earth, demonstrating similar irregular pits as mapped on the Top Basalt surface in the Skoll3D data.

Conclusions

High-resolution 3D seismic data are highly beneficial for scientific drilling planning and operations, and subsequent core-log-seismic integration in the deep oceans. We used site survey data from the CAGE20-4 cruise on the mid-Norwegian margin to optimize drilling operations at the Modgunn Vent and Mimir High sites during IODP Expedition 396, ensuring high recovery of the targeted Paleocene-Eocene transition. Post-drilling 3D data acquired on the Skoll High reveal a complex 3D top basalt surface, divided into a pitted and a faulted domain, formed during wetland and subaerial basalt emplacement environments respectively.

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