P-Cable High Resolution 3D Seismic – Case Study and Recent Advances

Frode N. Eriksen [a,], C. Berndt [b], G.J. Crutchley [b,c], J. Karstens [b]*
[a] P-Cable 3D Seismic AS, Oslo Innovation Centre, Gaustadalléen 21, 0349 Oslo, Norway
[b] GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany
[c] GNC Science, Lower Hutt 5040, New Zealand
** Corresponding Author. Email address: frode@pcable.com (F.N. Eriksen), www.pcable.com*

Summary

High resolution shallow marine 3D seismic data is of great interest for both the academia and the industry as it can uncover small spatial features not imaged by conventional 3D or high resolution 2D seismic data.

The patented P-Cable system consists of multiple streamers attached to a cross cable towed perpendicular to the vessel's steaming direction. The system is versatile and has proven to be a cost effective method for acquisition of small 3D data-sets. The system is under constant development and recent advances include upgrade of streamers and broadband processing.

Introduction

The P-Cable 3D seismic system has been developed since 2001 with principal aim to provide a more flexible and cost effective technique for 3D imaging of the shallow sub-surface. Worldwide, more than 60 3D data-sets have been acquired with different versions of the P-Cable system. In 2012 and 2014 commercial surveys were conducted in the Barents Sea (*Figure 1*). The primary objective was imaging of shallow hydrocarbon reservoirs and related geology to aid the petroleum industry in their ongoing search for commercial hydrocarbon accumulations in the region. Several academic surveys have been conducted in the same region, although mainly focusing on fluid flow features such as gas hydrates, shallow gas pockets and fluid venting systems (e.g. Hornbach et al., 2012; Petersen et al., 2010).

Detailed mapping of the sub-surface is important for several reasons. A range of geological features such as shallow fluid flows and gas pockets, gas hydrates and faults represent significant geohazards for hydrocarbon exploitation and are therefore important to identify. Due to large bin size and potentially long offsets in conventional 3D seismic data, this technique have a limited potential for high resolution imaging of the shallow sub-surface. In contrast, the P-Cable system offers short-offset data with possibilities for significant smaller binning size compared to conventional 3D seismic.

The potential of the high resolution P-Cable system is illustrated by a case study from off-shore Montserrat, an island within the Lesser Antilles Volcanic Arc.

Method

The patented P-Cable system consists of multiple streamers attached to a cross-cable towed perpendicular to the vessel's steaming direction. It typically consists of 12 to 24 streamers with a separation between 6 to 12 m. The length of the streamers usually varies from 25-50 m with small group intervals (3 m). A schematic figure and typical specifications are shown in Table 1 (*Figure 3*). Due to short source-receiver distance (50-150 m) all of the near offset signals are recorded. Such acquisition geometry results in data with 1-2 m vertical and 3-6 m horizontal resolution in the final processed cube.

Conventional 3D seismic acquisition technology relies on long streamers, large sources and big vessels. In contrast, the P-Cable system is lightweight and acquisition can be performed using small vessels. Efficient deployment, recovery and easy ship maneuvering makes it possible to acquire several small 3D datasets (i.e. 50 km^2) in a relatively short amount of time.

Case Study – Offshore Monserrat

The P-Cable data presented in this study was acquired off-shore eastern Montserrat by GEOMAR in 2010 (*Figure 2*). The Soufrière Hills volcano on Montserrat is used as a reference for understanding volcanic processes and is one of the most investigated volcanic arcs in the world (Druitt and Kokelaar, 2002; Wadge et al., 2010). The data-set is reported to be the first ever 3D seismic data acquired over the volcanic landslide deposits (G.J. Crutchley et al., 2012; Karstens et al., 2013). Based on seismic reflectivity, three different deposits were identified in the data-set i.e. Deposit 1, Intermediate Unit and Deposit 2 as shown in *Figure 3*.

Deposit 1 is characterized by non-coherent low amplitude reflections that exhibits hummocky seismic stratigraphy. The overall appearance of the deposit indicates that deposition occurred as one single event. However, this unit does contain some local continuous internal reflections (*Figure 3B*, concave-down reflections) but those are only traceable up to few hundred of meters only. Multiple blocks can also be observed in this deposit.

The Intermediate Unit, separating Deposit 1 and 2 exhibits distinct continuous high amplitude reflections in contrast to the other deposits. No blocks are observed within this seismic facies. This set of reflections are similar to the recent pyroclastic deposit on top of Deposit 1 (*Figure 3C*) and is interpreted to represent pyroclastic deposits. Similar to Deposit 1, this unit also thins towards the distal side. Lens-shaped seismic facies are observed in this sequence (*Figure 3C, D*). These facies are traceable within the whole dataset and get narrower and thinner away from the Montserrat.

Deposit 2 displays a non-coherent and low-amplitude seismic signature. Towards the East of the profile (*Figure 3A*), it is situated above well-stratified sediments. Further west, continuous reflections of the sediments truncate against the non-continuous volume of the Deposit 2. Similar to Deposit 1 this deposit was interpreted to represent a debris avalanche, however it a more complex emplacement history is suggested.

The P-Cable 3D data allows for detailed interpretation of the off-shore deposits contributing to new insights into submarine landslide emplacement off-shore Montserrat. Based on observations from the seismic cube Deposit 1 is interpreted to represent a debris avalanche deposit, the Intermediate Unit particle laden mass flow deposit derived from pyroclastic flows and Deposit 2 a volcanic flank collapse debris flow deposit (G.J. Crutchley et al., 2012).

Recent Advances

Since the first proto type testing in 2001, the P-Cable system has been continuously developed and improved. New acquisition and processing workflows have been established to ensure the highest possible data quality.

Until 2012, P-Cable data was acquired using liquid streamers with threshold to record lower frequencies up to 18 Hz. Similarly, conventional seismic data processing was applied to the data. It included 3D binning, f-k filter, stacking and migration. The processed data has dominant amplitude spectrum of 18-200 Hz.

In 2014, more than 550 km^2 of multi-client P-Cable data was acquired in the Norwegian Barents Sea region using solid-state streamers with improved noise characteristics and capabilities of recording low frequencies. Together with tailor made new deghosting and frequency enhancement procedures this have allowed an increase of the frequency bandwidth up to 5-250 Hz.

Due to increased frequency bandwidth, P-Cable data holds a great potential in delineating thin reservoirs as it is sensitive to small amplitude changes. A comparison of the conventional 3D and overlapping P-Cable datasets from the Hoop Area in the Barents Sea is given in *Figure 4*. Sub-figures 1(a) and 2(a) show the same 3D dataset processed conventionally and using deghosting technique 'Clari-Fi™' developed by TGS. Sub-figure 3(a) shows deghosted P-Cable data using the same technique. As *Figure 4* illustrates, only the P-Cable data is able to properly delineate the fluid contact i.e. flat spot.

Conclusions

P-Cable 3D technology offers a superior image of the subsurface. The combination of high vertical and horizontal resolution with all the added benefit of 3D enables imaging far better than conventional 3D and high resolution 2D. The technology has the potential to become the preferred exploration technique for shallow reservoirs and for other geotechnical and environmental considerations.

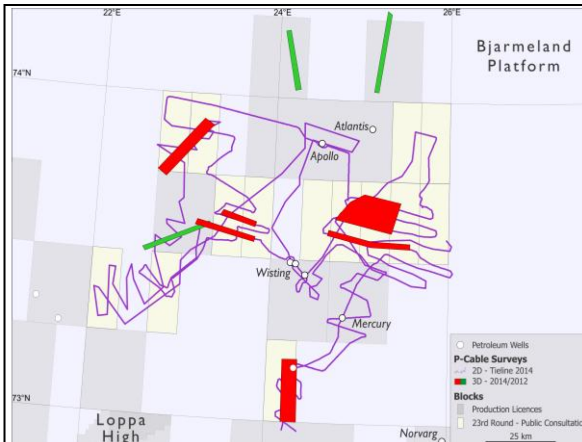


Figure 1: Location of P-Cable datasets acquired in the Norwegian Barents Sea in 2012 (green) and 2014 (red and purple)

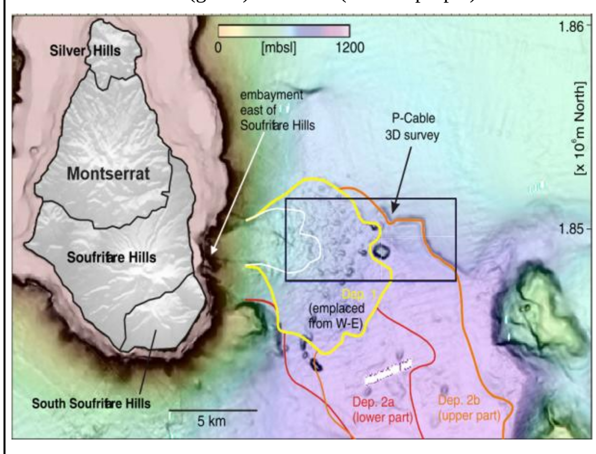
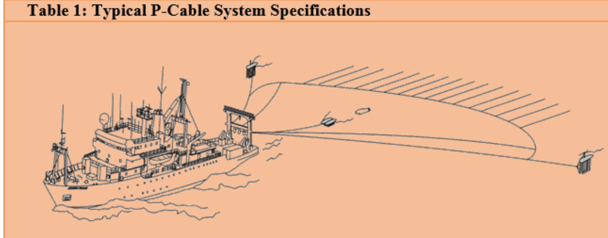


Figure 2: Rectangle showing the location of the P-Cable 3D survey Offshore-Montserrat (modified from G.J. Crutchley et al., 2012)

P-Cable High Resolution 3D Seismic

Table 1: Typical P-Cable System Specifications



Schematic Diagram of P-Cable System (P-CABLE™) *(Planke and Berndt, 2004)*
Norway Pat. No. 317652, UK Pat. No. GB 2401684, US Pat. No.7.221 .620 B2.

Number of Streamers: 12 - 24 m
Streamer Length: 25 - 50 m
Streamer Spacing: 3 - 12 m
Source-Receiver Spacing: 50 - 100 m
Receiver Interval: 3 m
Frequency Content: 20 - 350 Hz
Bin Size: 3×3 or 6×6 m
Horizontal Resolution: 3 - 6 m
Vertical Resolution: 1 - 1.5 m
Deployment/Recovery: 1 - 2 hours
Acquisition Efficiency: 14 km²/day

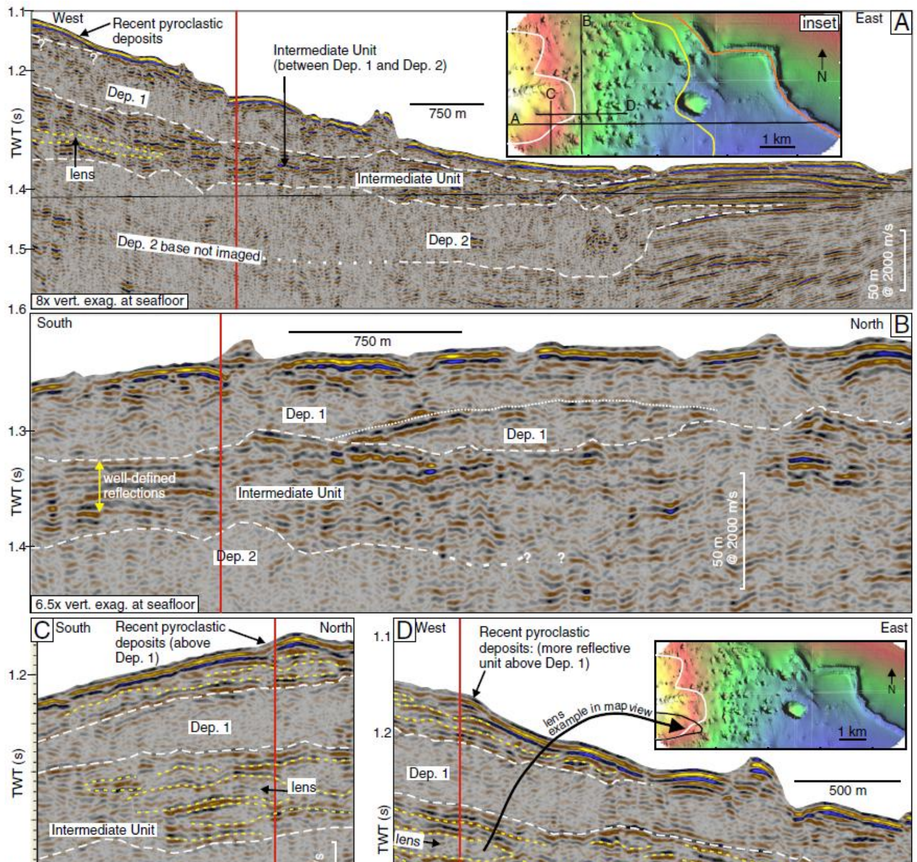


Figure 3: Four intersecting profiles extracted from the 3D volume are shown (A-D). Bold black lines in the inset in figure A show the location of the profiles. A) Inline showing Deposit 1, 2 and the Intermediate Unit. Broken white lines show the boundaries of interpreted horizons. Low reflectivity lens in Intermediate Unit is shown by broken yellow line. B) Crossline through the dataset. Concave-down reflections in Deposit 1 are shown by fine dot line. C) Crossline showing recent pyroclastic deposits overlying Deposit 1. Well-defined lens shape reflections in Intermediate Unit and recent pyroclastic deposits are highlighted by broken yellow lines. D) Lens in Intermediate Unit thin away from west to east and exhibit lobe-shape structures (G.J. Crutchley et al., 2012)

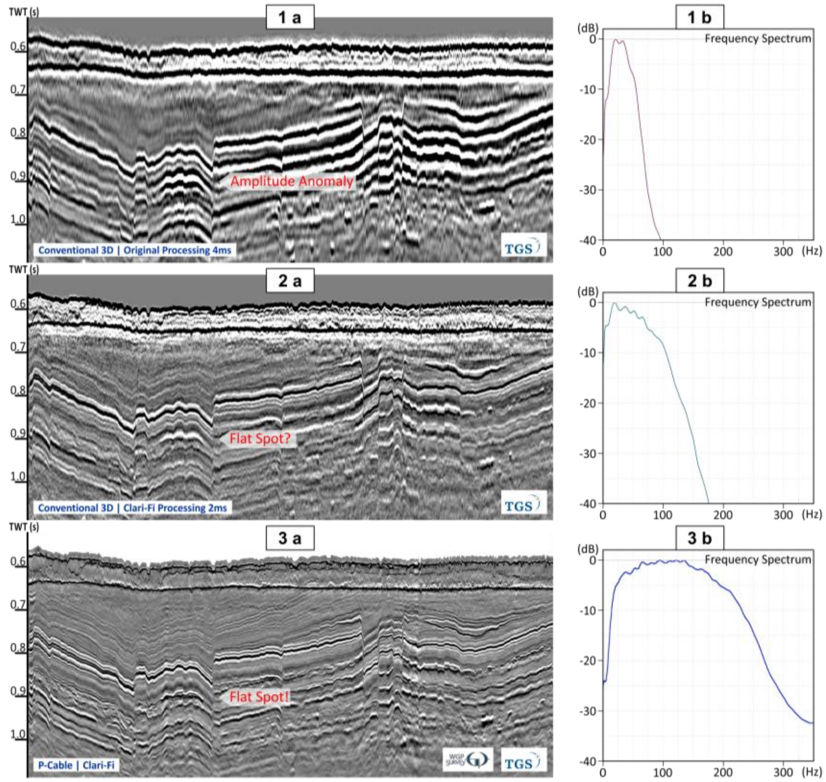


Figure 4: A comparison of conventional 3D dataset processed using normal routine (1a) and deghosted using Clarif-Fi™ 2(a). P-Cable data processed using Clari-Fi™ is given in Figure 3(a). 1(b), 2(b) and 3(b) show the frequency spectra of the three data-sets.

References

Crutchley, Gareth J., Jens Karstens, Christian Berndt, P. J. Talling, S. F. L. Watt, M. E. Vardy, V. Hühnerbach et al. "Insights into the emplacement dynamics of volcanic landslides from high-resolution 3D seismic data acquired offshore Montserrat, Lesser Antilles." *Marine Geology* 335 (2013): 1-15.

Druitt, Timothy H., and B. Peter Kokelaar, eds. "The eruption of Soufrière Hills volcano, Montserrat, from 1995 to 1999." Geological Society of London, 2002.

Hornbach, M. J., Bangs, N. L., and Berndt, C. (2012). Detecting hydrate and fluid flow from bottom simulating reflector depth anomalies. Geology, 40(3), 227-230.
Karstens, J., Crutchley, G.J., Berndt, C., Talling, P.J., Watt, S.F.L., Hühnerbach, V., Le Friant, A.L., Lebas, E., Trofimovs, J., and Watt, S.F.L., 2013. Emplacement of pyroclastic deposits offshore Montserrat: Insights from 3D seismic data. Journal of Volcanology and Geothermal Research, v. 257, p. 1-11

Petersen, Carl Jörg, Stefan Bünz, Steinar Hustoft, Jürgen Mienert, and Dirk Klaeschen. "High-resolution P-Cable 3D seismic imaging of gas chimney structures in gas hydrated sediments of an Arctic sediment drift." Marine and Petroleum Geology 27, no. 9 (2010): 1981-1994.

Planke, S., and Berndt, C., 2004. Apparatus for seismic measurements. UK Pat. No. GB 2401684.

Wadge, Geoffrey, R. Herd, G. Ryan, E. S. Calder, and J-C. Komorowski. "Lava production at Soufrière Hills Volcano, Montserrat: 1995–2009." Geophysical Research Letters 37, no. 19 (2010).