Extreme Mirror Imaging—Imaging high order multiples following the Hugin shakedown test

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Abstract

If you deploy an ocean bottom node at 450m water depth over a thin layer of sediments over Granite basement, would you expect to image a seabed granite outcrop 2km away? Surprisingly, the answer is Yes. We did just that. We see the distant granite outcrop on high order multiples and on refraction. This is confirmed by modeling.

Introduction

Excellent data are acquired by surface towed streamers. However, streamers have significant limitations. They cannot be operated safely in obstructed oil fields. Multiples are often a major problem. Streamers are subject to drift which may compromise repeatability for seismic reservoir surveillance (4D) and they cannot record shear waves.

Because of the limitations of streamers there is a growing demand for Ocean Bottom Seismometers. OBS can be done with either Ocean Bottom Cables (OBC) or with Ocean Bottom Nodes (OBN). (Fig. 1).

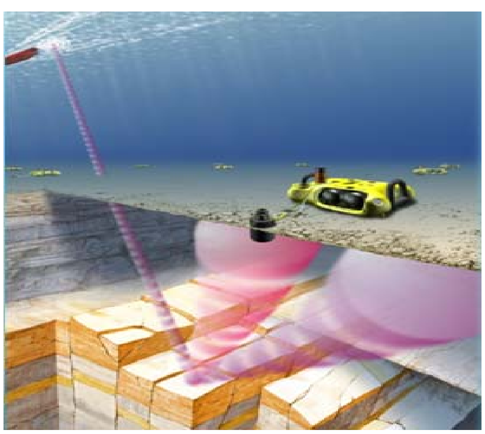

Fig. 1: Ocean Bottom Nodes recording reflections from geological formations and reservoirs. Some of the P waves emitted by the source are reflected as P waves and some are converted and reflected as shear waves. Note the sparse array of nodes on the seabed. The shot geometry , on the other hand, is dense.

Because OBS record both pressure and particle motion, they enable separation of up and down going waves at the seabed and therefore provide opportunities for demultiple and for imaging with multiples.

Multi-component streamers also enable separation of up and down waves but because the data are recorded near the sea surface, imaging with multiples is much more limited than with OBS in deep water. In addition, OBS provides full azimuth data naturally. Wide azimuth is achievable with streamers but in a more limited way. OBS can be operated safely in the presence of surface obstructions with OBN having an additional advantage over OBC in the presence of seabed obstructions and in deep water.

Nodes, if planted by a Remotely Operated Vehicle, also have better coupling and provide better data than nodes and cables which are not planted. Cables can be trenched at significant additional cost but the trench is a disturbed environment and trenched OBC data is not as high as planted OBN data. One type of ROV planted node is the CASE-Abyss (Fig 2).

Fig. 2. Each ocean bottom node has an external planted sensor package containing a hydrophone and 3 geophones in vertical and two horizontal orientations.

A crew operating such nodes must have the following elements: nodes, ROV, source, and optionally, streamers. These elements can be deployed on one or more vessels. To meet the growing demand for OBS data, all the above elements were mobilized on the seismic research vessel the Hugin Explorer (Fig 3).

The vessel was designed to operate in obstructed oil fields (Figs 4a & 4b).

Fig. 3: The Hugin Explorer during the shakedown test offshore Norway. She has 500 ocean bottom nodes (OBN), Remotely Operated Vehicle (ROV) , dual source, and a streamer.

Towards the end of her rigging, the Hugin Explorer left the shipyard at Egersund to conduct a test after which she returned to Egersund to complete her mobilization. The location for the shakedown test was selected for its proximity to the shipyard (Fig 5).

Nodes were deployed using an ROV with a special planting contraption (Fig. 6). Although the test location was not selected for any geological interest, interesting data was acquired. Little was known about the location except that the water depth was 450m and there was a thin layer of soft sediments over granite basement.

Fig 4b. The Hugin Explorer was designed to work safely in obstructed oilfields--the bridge is at the front and the helideck does not obstruct the view from the bridge.

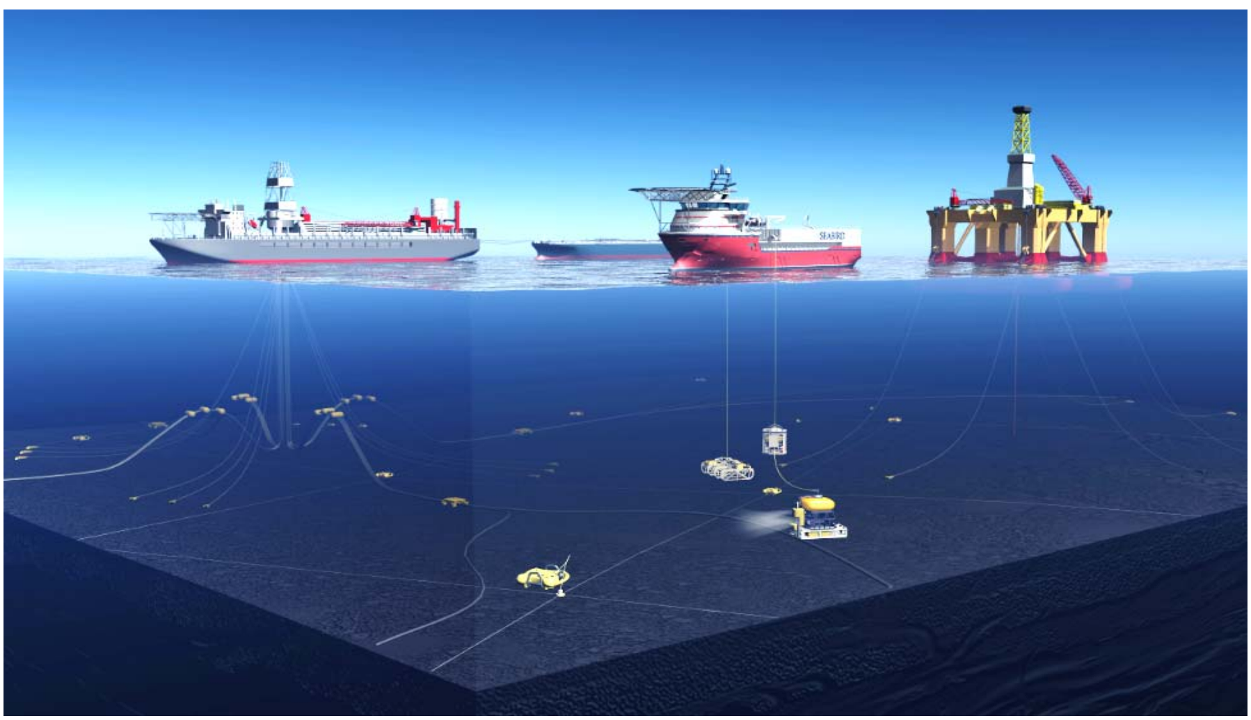

Fig 4a. Surface and subsea obstructions are no longer a major challenge in getting seismic over the reservoir with the use of ocean bottom nodes.

Fig. 5: Hugin shakedown test location. Off Egersund in the south of Norway.

Fig. 6: ROV planting external sensor package during the shakedown test.

Field Data

There are very few primary reflectors, essentially the seabed and the top Granite. The four component data (Fig 7) clearly shows P waves on the hydrophone and the vertical components and shear waves on the two horizontal components. As usual in high latitudes multiples dominate the data. Conventionally, only primary reflections are considered signal and multiples are considered noise. However, simple mirror imaging reveals the potential of imaging with the multiples (Fig 8). Five orders of multiples are seen. The illumination is improving as the number of bounces increase. However the signal to noise ratio is getting worse with multiple order. It seems that the best image is provided by the third bounce. The image of a feature which looks like an outcrop appears (Fig 9). The effect of the outcrop is also seen on the refraction (Fig 10).

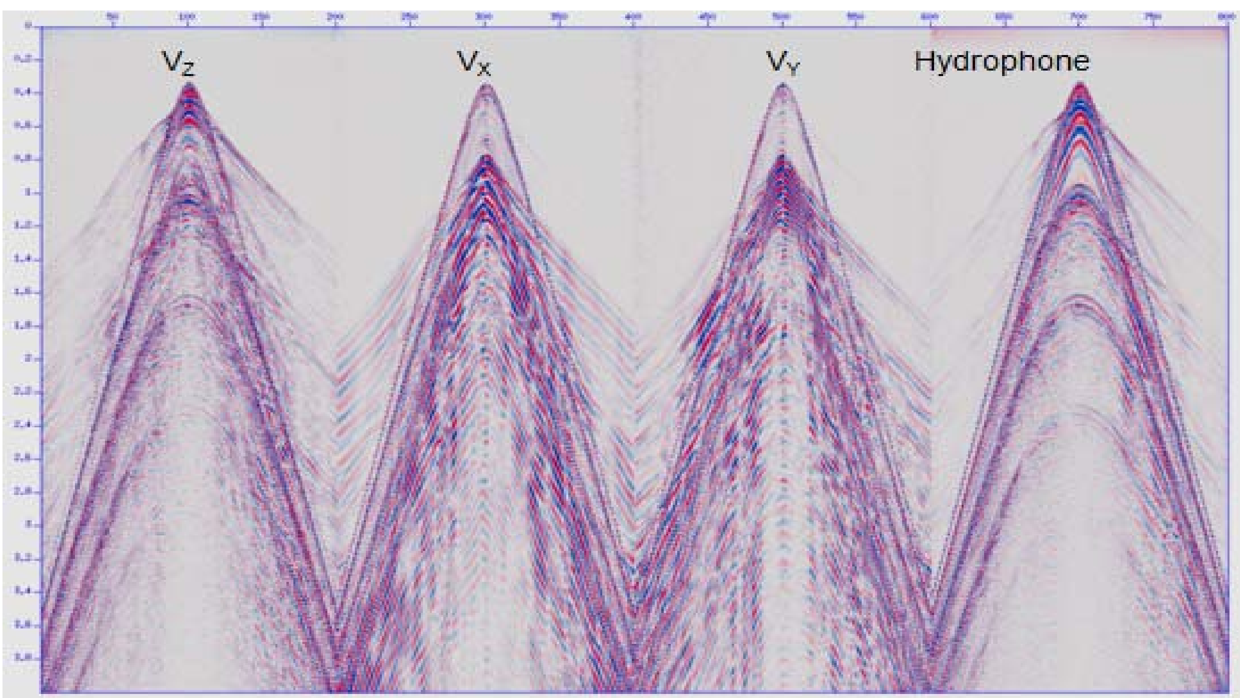

Fig 7: Shakedown test common receiver gather. 5km Offset. 50m Shot Interval. No Processing except gain. Note the P waves recorded on the Hydrophone and Vertical components and the shear waves recorded on the horizontal components Vx and Vy.

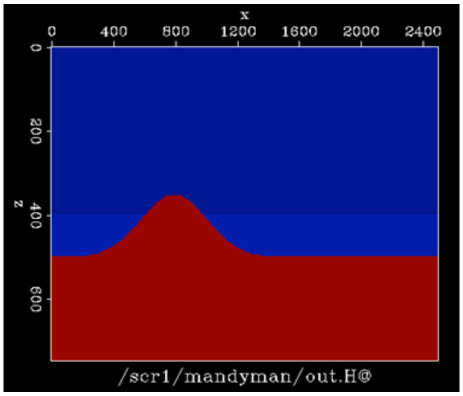

Fig. 11: Velocity model for wave equation finite differencing modeling.

Modeled Data

To verify the interpretation of the data as a granite outcrop, we used wave equation modeling to generate data with the supposed earth model (Fig 11). The synthetic data were processed in a similar way to the field data (Figs 12 -14).

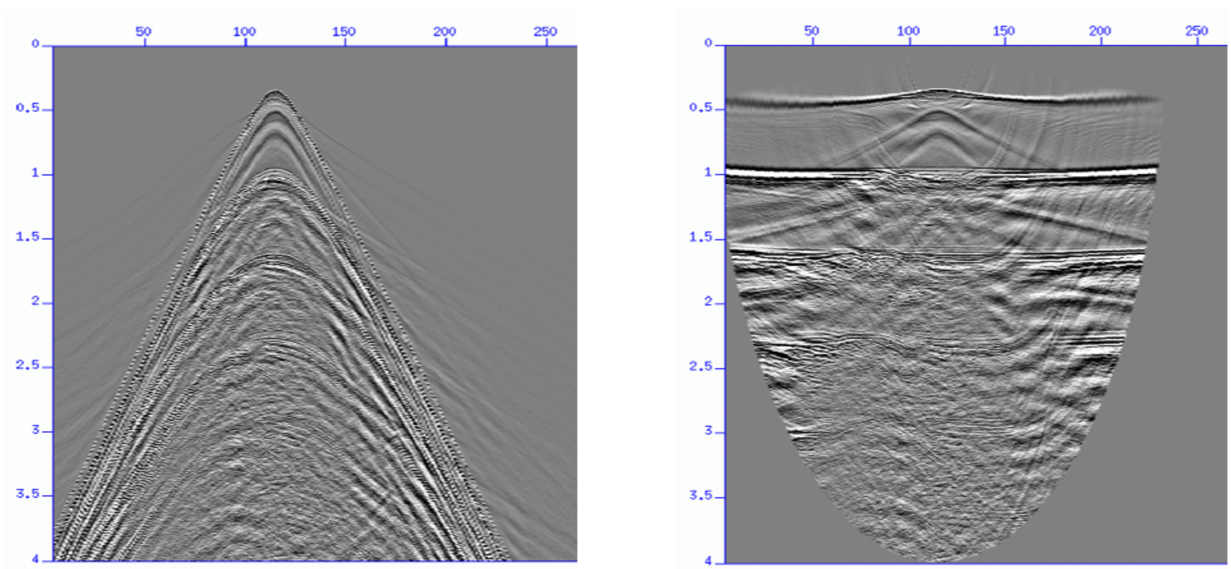

Fig 8. Common receiver gather before (a) and after (b) NMO with water velocity. Granite outcrop about 2 km away from the node is seen on the refraction in (a) and on the multiples in (b).

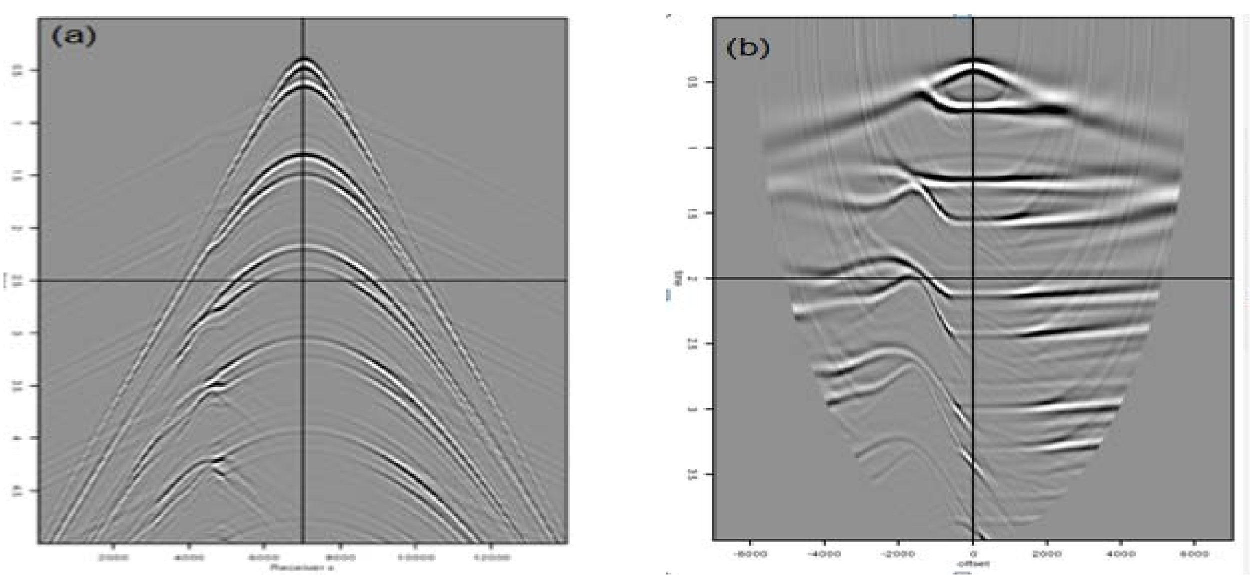

Fig 12. Common receiver gather before (a) and after (b) NMO with water velocity. Granite outcrop about 2 km away from the node is seen on the refraction in (a) and on the multiples in (b). Compare to Fig 8.

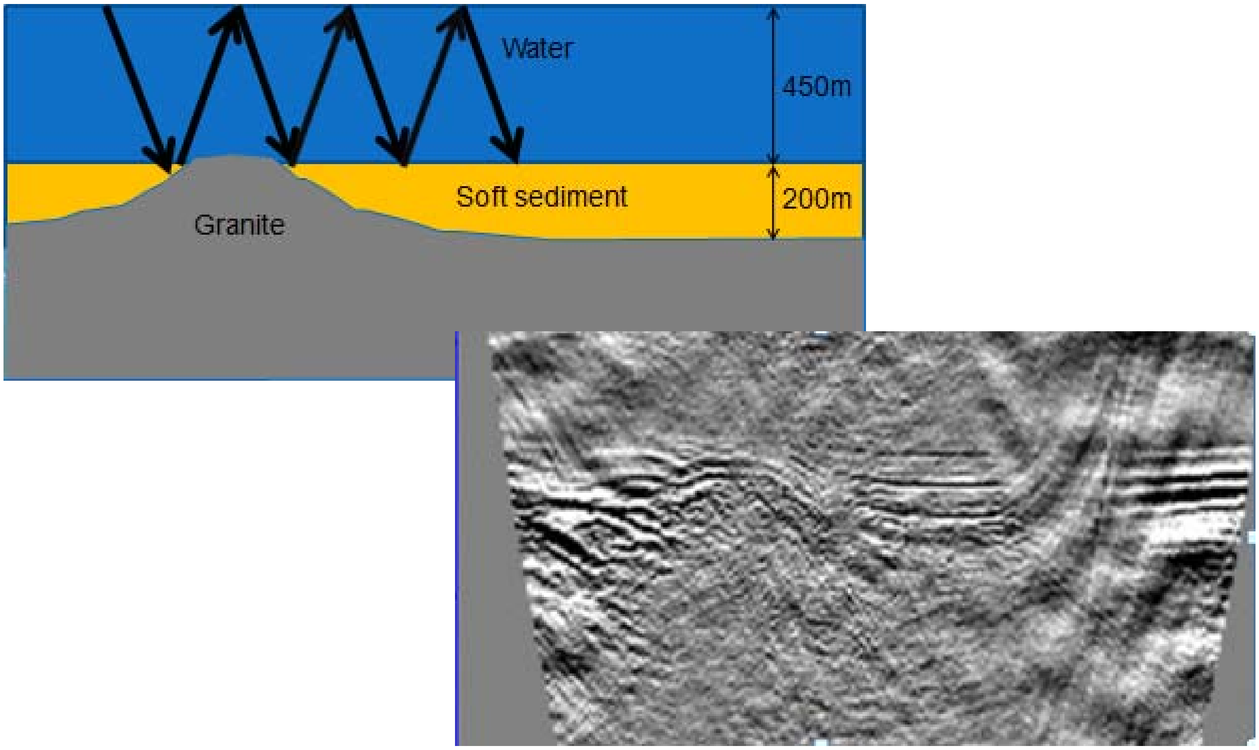

Fig 9. Details from Fig 8b.   Granite outcrop about 2 km away from the node is seen on the multiples.

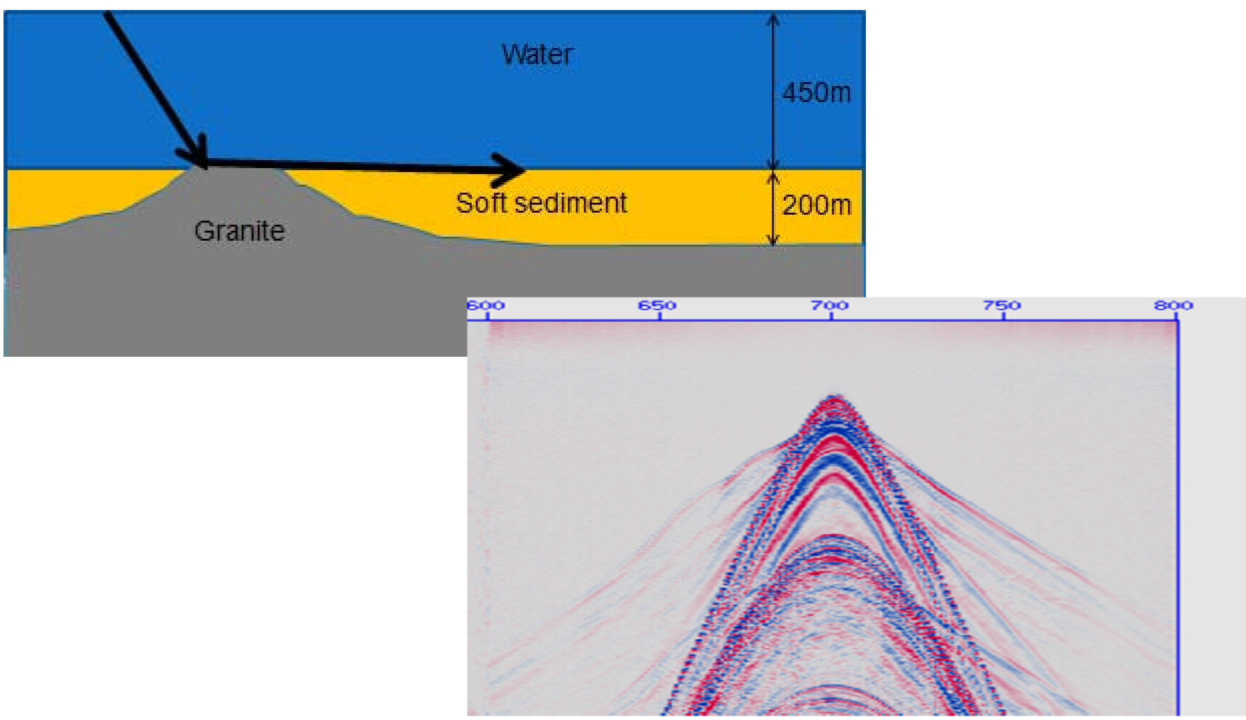

Fig 10. Details from Fig 8a.   Granite outcrop about 2 km away from the node is seen on the refraction.

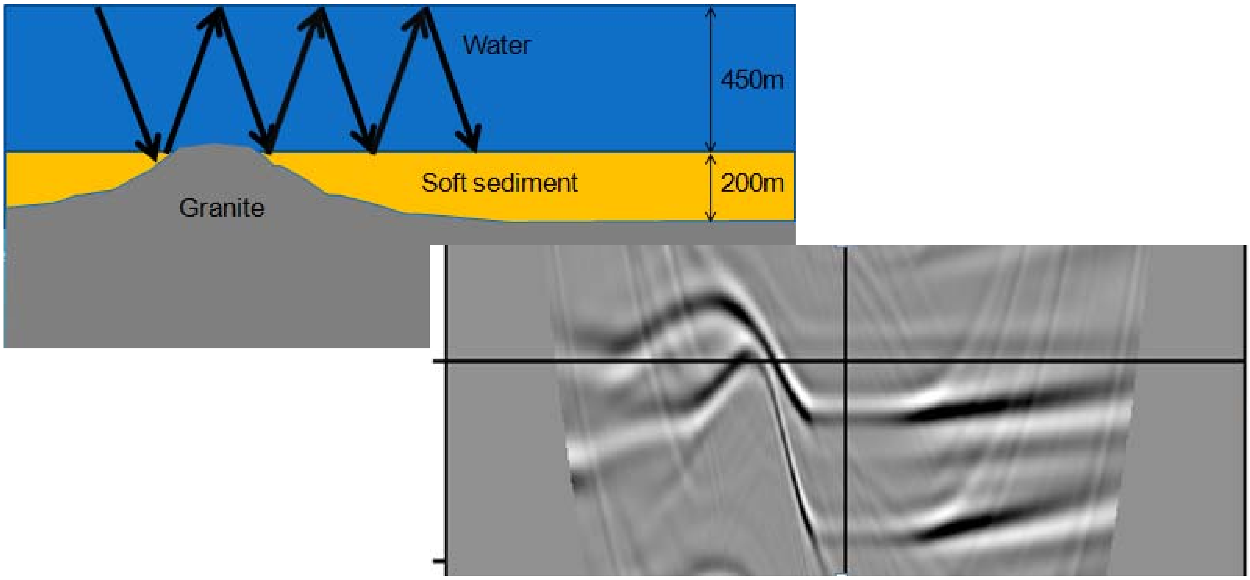

Fig 13. Details from Fig 12b. Granite outcrop about 2 km away from the node is seen on the multiples.

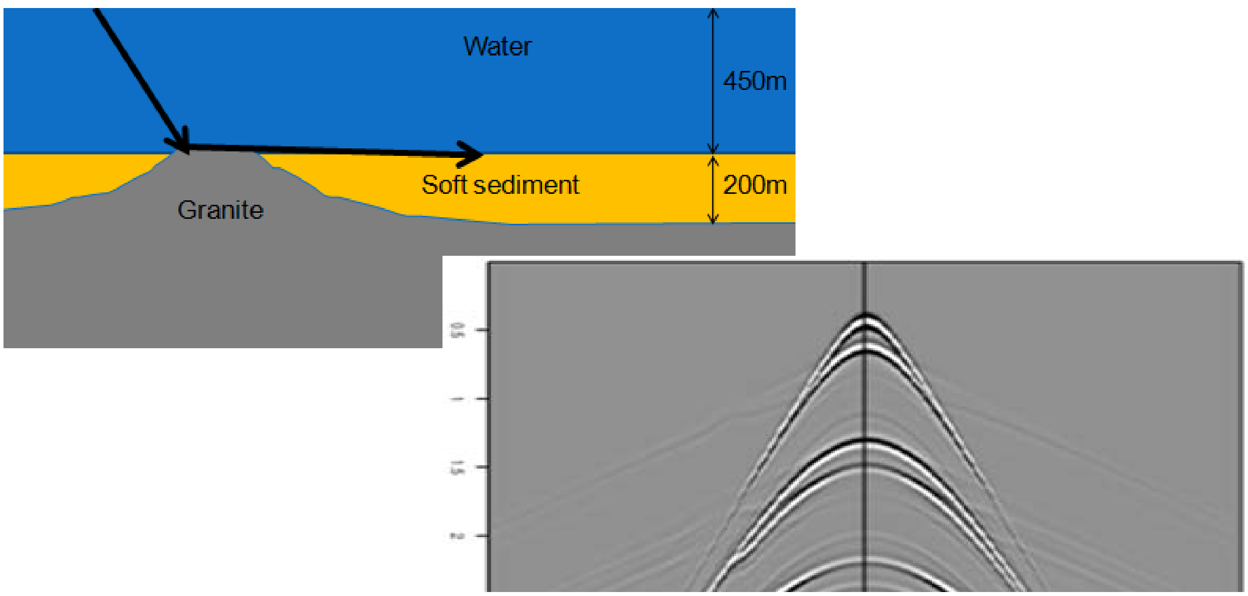

Fig 14. Details from Fig 12a. Granite outcrop about 2 km away from the node is seen on the refraction.

Summary

We present a number of innovative acquisition and analysis methods. The data were acquired with ocean bottom nodes which is a new acquisition method specifically designed to provide high quality data for reservoir characterization and surveillance.

The data example has mostly multiples. The primary reflections in this case are useless. Therefore, the processing of the data is based on multiples and refractions. The processing method is a hybrid between imaging and modeling. The data are partially imaged to a stage that features can be recognized. Then synthetic data are produced and processed just the same as the field data.

Having done all that on data acquired for the purpose of operational and equipment shakedown is just a small demonstration of the potential of high quality ocean bottom node data and the power of innovative usage of simple processing and modeling methods.