

Converted waves for sub-basalt imaging?

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Summary

In areas with extensive basalt coverage like the Atlantic Margin these high-velocity layers hamper the imaging of possible hydrocarbonate reservoirs beneath them. One suggested solutions to this imaging problem is the use of locally-converted waves. We show that these waves with mode conversions at the basalt interfaces are too difficult to be utilized for imaging sediments below a basalt layer. This is due to their weak amplitudes and additional noise in real data recordings. The calculation of synthetic seismograms shows that two other converted waves might have the ability to gain information of sub-basalt reflectors. One wave type is the PS-mode which travels down as P-wave and up as S-wave. The second type is the wave with only S-modes below the seabed. Both waves show strong amplitudes especially on calculated OBC-data.

Introduction

In the North Atlantic Margin, flood basalts and sills form a high impedance contrast with the surrounding sediments due to their high velocities. Therefore less energy of an incident P-wave is transmitted through such a basalt layer and reflections of the same mode from beneath have weak amplitudes Furthermore multiple reverberations, mainly between sea-surface, seabed and basalt-top, hide weak responses from sub-basalt interfaces (Longshaw et al., 1998). Additionally the incident P-wave is refracted at smaller offsets at the top-basalt boundary only allowing S-modes to travel further down (Hanßen and Li, 1999a).

These factors make the processing of short streamer data with standard processing methods very difficult. To gain information about the structure beneath such basalts three main seismic wave types may be addressed. First the near offsets for P-waves but where the removal of multiple is critical (Druzhinin et al., 1999). A second target could be the refracted waves at far offsets (Richardson et al., 1999), which can only map high impedance contrasts beneath the basalt. A third wave type is the converted wave, which could be observed at mid-range offsets (Purnell et al., 1990).

Due to the high P-wave velocity contrast between basalts and the surrounding sediments an incident compression wave is likely to transmit more energy through this layer by changing to an S-wave. This might happen at the

top and the bottom interface of the basalt on the way up and again on the way down. In ideal circumstances this locally converted wave can even exceed the amplitude of a pure P-wave as shown by Hanßen and Li (1999b).

Effective Reflection Coefficient

To test these assumptions we used a five layer off-shore model with a high-velocity layer inter-bedded between sediments and sandstone (Figure 1).

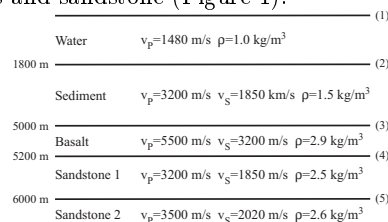


Fig. 1. Off-shore model with inter-bedded high-velocity layer.

The target horizon (5) is an interface beneath the basalt where the P-wave velocity increase is about 300 m/s. Initially the S-wave velocity of the basalt matches the P-wave velocities of the surrounding rocks. Former studies show that this is the ideal case for a P to S conversion at the basalt boundaries Hanßen and Li (1999b).

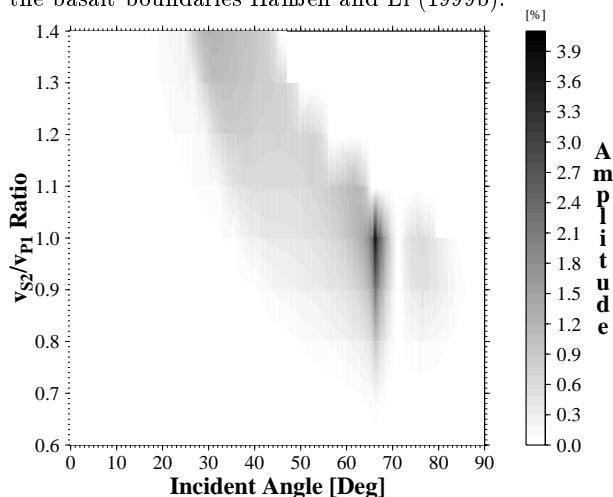


Fig. 2. Effective reflection coefficient for the wave travelling only in S-mode through the basalt layer of model 1 (2PdSdPd) for different S-wave velocities inside the Basalt.

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To investigate the amplitude behaviour of locally converted waves in a more realistic case, we now changed the velocities of the basalt and calculated the response from the target interface. Figure 2 shows the amplitudes for a wave with symmetrical ray-path travelling down to interface 5 from the sea surface. The wave travels as P-mode through the first two layers, has an S-modes only inside the high-velocity layer and transforms back to P-mode to reach the target interface (2PdSdPd). The maximum amplitude is 4.1 % of the input amplitude.

Furthermore the wave with S-modes only inside the basalt is restricted to a narrow band of the incident angle, and the amplitude decreases rapidly if the S-wave velocity inside the basalt doesn't match the surrounding P-wave velocities.

The comparison of this wave type with the pure P-wave is shown in Figure 3. The amplitude of the P-wave at near offsets exceeds the one of the locally-converted wave not only where the S and P-wave velocities don't match but also at a Ratio of $v_{s2}/v_{p1} = 1$.

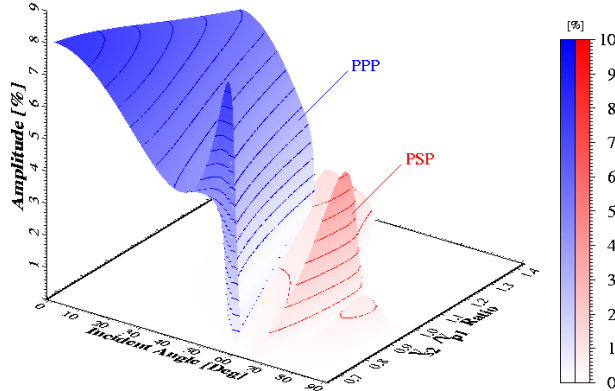


Fig. 3. Effective reflection coefficient for the P-wave (PPP) and the locally-converted wave (PSP) through model 1 with varying S-wave velocity inside the Basalt.

This can also be seen in the synthetic seismogram (Figure 4) for this ideal model in Figure 1. The amplitude of the pure P-wave (4Pd) at near offsets is bigger than the amplitude of the locally-converted wave (2PdSdPd). At offsets beyond 9000 m only the converted wave is visible because the P-wave is refracted. The amplitude of 2PdSdPd is very weak as calculated before.

This also applies to the wave which travels only as S-mode below the top of the basalt (2Pd2Sd). The maximum amplitude of this mode is even weaker than the 2PdSdPd-mode and doesn't exceed 1 % as shown in Figure 5.

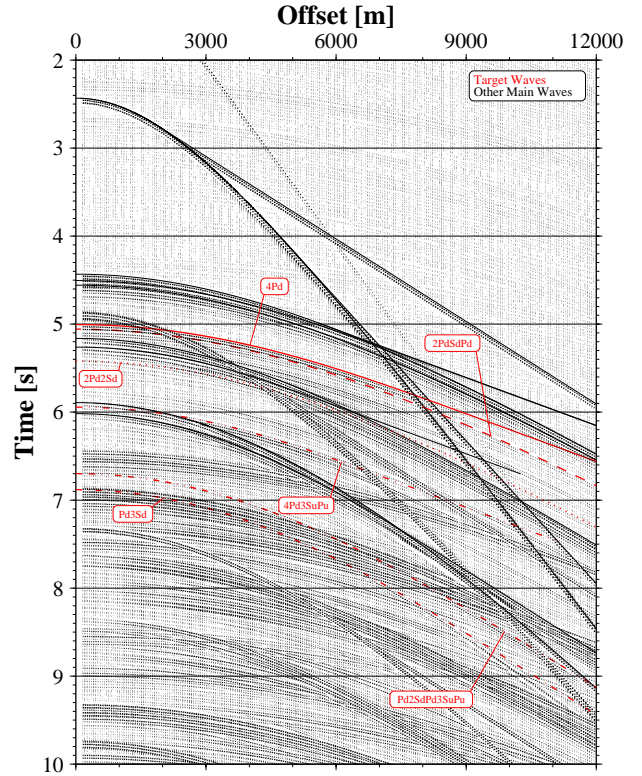


Fig. 4. Synthetic seismogram of the five-layer model showing traveltime curves for P-wave reflections and annotated, waves of the target interface (5).

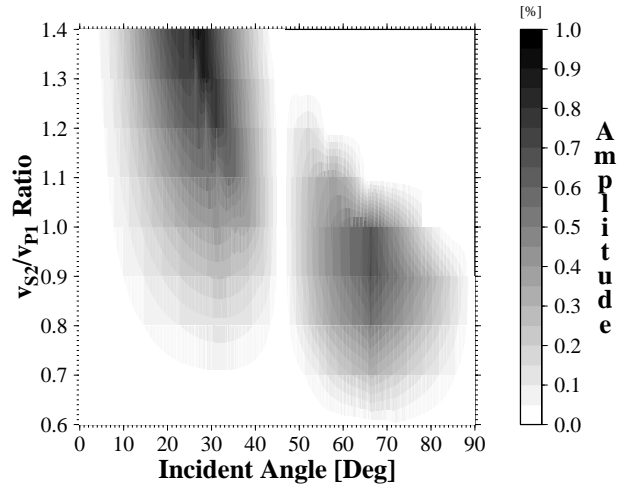


Fig. 5. Effective reflection coefficient for the wave travelling only as S-mode below the top-basalt interface of model 1 (2Pd2Sd) for different S-wave velocities inside the Basalt.

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This shows that both the locally converted waves 2PdS-dPd and 2Pd2Sd have too weak amplitudes to be recorded. Especially in real data where noise, multiples and refracted waves hide their responses.

Streamer Data and Synthetics

The synthetic seismogram in Figure 4 also shows that other converted waves can have bigger amplitudes than the locally-converted modes. A stronger response with a maximum around 6000 m offset is observed from the PS-mode (4Pd3SuPu). Two other strong modes at far offsets were identified as pure S-wave below the seabed (Pd3Sd) and a variation of it with a P-wave part on the way down below the basalt (Pd2SdPd3SuPu).

To verify these findings we calculated full-waveform shot-gathers with velocity models obtained from real data, shown in Figure 6. Figure 7 shows the synthetic seismogram with 12 km offset and a velocity model from the Faroes area. To examine responses from beneath the basalt we included three interfaces with increasing impedance contrast.

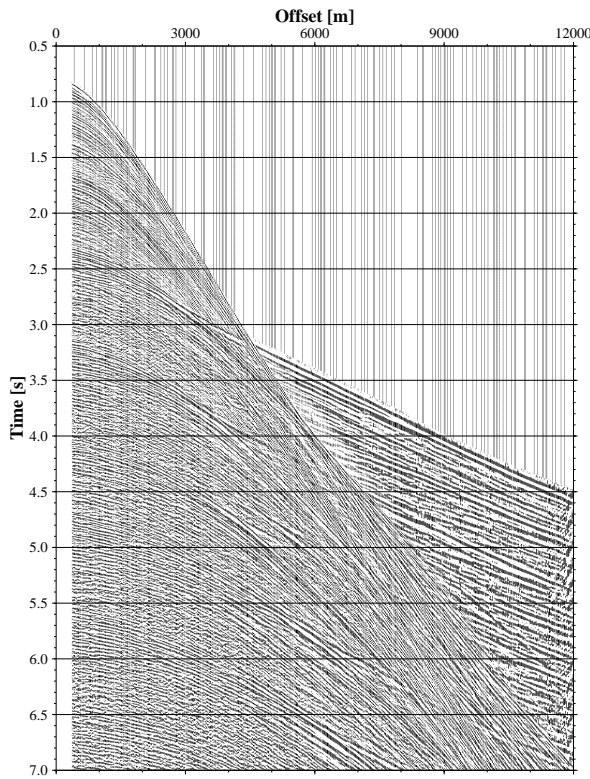


Fig. 6. Real shot-gather of a sea surface recording with a 12 km Streamer (courtesy of Veritas DGC).

Straight lines are pure P-wave reflections, where the dark blue lines are the traveltimes of the top and the bottom of a basalt layer. The other curves indicate interfaces from below the basalt. Red for a weak contrast ($\delta v_p = 200 m/s$), green for a strong one ($\delta v_p = 800 m/s$) and light blue for a basement ($\delta v_p = 1200 m/s$).

All three interfaces can be seen at near offsets in their P-wave responses. That is the only mode which can be discriminated of the weak contrast. The strong contrast (green) can also be detected in the PS-converted wave (7Pd6SuPu) but is disturbed by multiples. A clear response of this interface can be seen in the pure S-mode below the seabed (P6s). The big velocity change at the top of the basement (light blue) can be seen in almost all waves except the locally converted waves.

OBC Synthetics

To evaluate the PS-mode and pure S-wave we calculated the seismic wavefield for a Ocean Bottom Cable (OBC) recording.

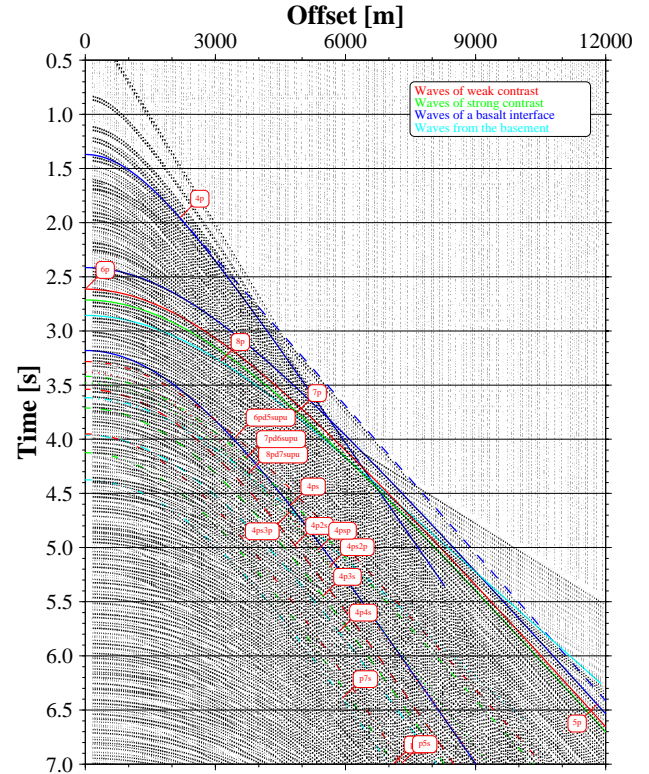


Fig. 7. Synthetic shot-gather of a sea surface recording for the Faroes area with superimposed traveltime curves for waves from 3 sub-basalt interfaces.

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The horizontal component of the OBC-data (Figure 8) shows more details than the calculated streamer data. All the above described wave modes are visible but also the PS-converted wave of the strong contrast (7Pd6Su) is now traceable over a long offset. But there is not much evidence of any converted wave of weak contrast despite synthetics without noise.

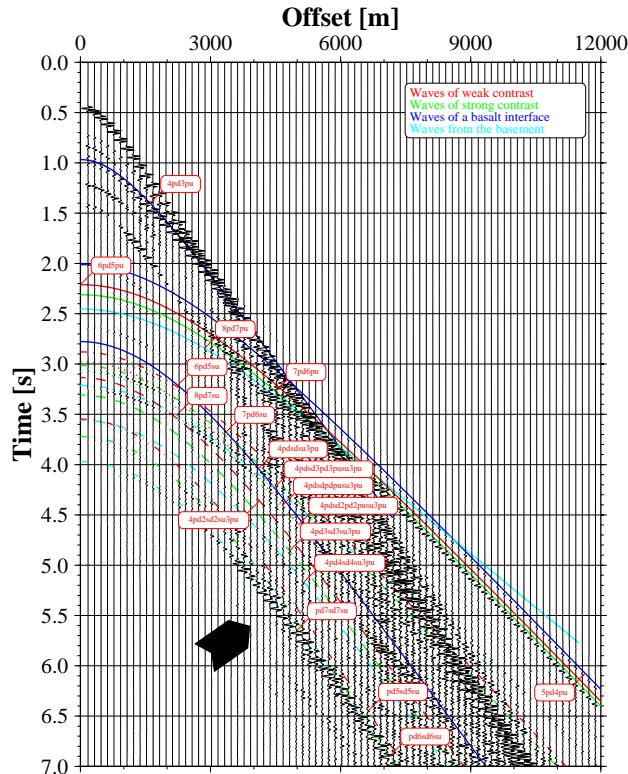


Fig. 8. Horizontal Component of a synthetic shot-gather including all multiples of a seabed recording for the Faroes with superimposed traveltimes.

Discussion and conclusions

We have shown that locally-converted shear-waves are difficult to be utilized to image below the base of a high-velocity basalt layer due to their weak amplitudes. It is therefore highly unlikely to find any significant locally-converted shear-wave energy in off-shore streamer data due to additional noise and in reality more complex geological settings.

Calculations of the effective reflection coefficient show furthermore that the amplitudes of pure P-wave reflec-

tions at near offsets are dominant compared to locally-converted waves.

Synthetic seismograms reveal that waves which travel purely as S-wave below the seafloor and waves which travel down as P-wave and up as S-waves have a potential to image beneath a high-velocity layer. To avoid a mode change and therefore an energy loss of these waves at the seabed an OBC or OBS recording is necessary.

Acknowledgement

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