Aiming towards imaging beneath basalt : multiple suppression offshore Faroe Islands

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Abstract

This paper discusses the successful suppression of surface related multiples from a marine seismic line recorded offshore the Faroe Islands in the Atlantic Ocean. The subsurface in this area is characterized by a mixture of igneous rocks and sediments. The presence of Tertiary basalt layers within the various sediments has created a very large acoustic impedance contrast. Propagation velocities within the basalt are much higher than those in the surrounding sedimentary layers. This dramatic difference results in a very poor imaging below the basalt. Additionally, the reflection data is contaminated by very strong multiples which mask any interpretable events beneath the basalt. In this paper some results are presented on the successful suppression of strong surface related multiples.

Introduction

The geographical location of the Faroe Islands is north-west of the United Kingdom and south-east of Iceland. These are a series of volcanic islands with a history of igneous activity that has placed lavas and sills within the various sediments. This specific situation with the igneous rocks and bodies results into a very poor recorded signal of seismic data related to the subbasalt structures. In the layers and areas above the basalt layer the amplitude and frequency of the signal is dramatically higher in comparison with the primary subbasalt reflected and imaged signals. From the recorded data it appears that there is a series of very strong surface related multiple recorded which makes it even more difficult for further interpretation. These surface related and strong amplitude multiples are of high frequency and are related to the layers above the basalt layers. As mentioned earlier, the presence of the basalt layer in the subsurface where the data was recorded makes subbasalt interpretation extremely difficult.

The waves that have been propagated through the subsurface and hit the basalt layer loose most of their high amplitude and frequency content after passing the basalt layer. Furthermore, a large amount of incident energy will refract and will be propagating along the basalt layer.

Surface related multiple elimination

Apart from the fact that the geological structures in this area makes it very difficult for subbasalt interpretation, the recorded data contains a series of strong multiples which mask the remaining very weak in amplitude and low-frequency content primaries. Here the method of surface related multiple removal procedure (Verschuur et al., 1992, Berkhout and Verschuur, 1997) has been used. This procedure requires the data itself as the multiple prediction operator. The quality of the signal related to structures above the basalt layer is relatively good. Therefore, since the quality of the original shot records is relative good for the upper structures, the estimation of the surface related multiples has been successful. Prior to the surface related multiples removal, some linear noise have been suppressed from the data, following by the near offset interpolation. The missing near offsets have been interpolated in the parabolic Radon domain (see Kabir and Verschuur, 1995).

This methodology of surface related multiple estimation and suppression makes a good estimate of the "near offset" multiples which appear to be the strongest multiples recorded along the marine line. After near offset interpolation, reciprocity was used to compose double sided data for a better surface related multiple estimate, as artifacts at the near offsets are thus avoided. These shot gathers were used as input to the procedure of multiple estimation. The application of the multiple estimation procedure and adaptive least squares subtraction of the multiples appears to be very effective on this marine dataset, as can be seen in the following example.

Example

In the following example, some results are shown on the surface related multiples estimates and suppression. The original shot gathers were each recorded along approximately 12 km of offset. These extreme long streamer cables have been used with the objective to use tomographic traveltime inversion to assist in building the depth velocity model. The discussion of the long offset recordings and inverting the traveltimes for the turning and refracted waves is beyond the scope of this paper. In the following experiment of multiple estimation, only 6 km offset has been used as maximum offset in the shot records. Three shot records have been selected along the line to illustrate the results and the effect of multiple suppression on the prestack gathers.

Figure 1 illustrates the result of surface related multiple removal procedure on three prestack shot gathers. From left to right, the orginal shot gathers are shown respectively the removed multiples folowed by the resulting shot gathers after surface related multiple suppression. At first glance, when studying the original shot records, a repetitive pattern can be observed of high-frequency content events. Furtermore it can be observed that the high-frequency signal of the events is quite strong in amplitude. As mentioned in the introduction, the surface related multiple elimination requires the data itself to make an estimate of the multiples. The middle part of Figure 1 shows the estimated multiples. From this picture, it can be concluded that most of the high amplitude multiples are concentrated in the first 2 km offsets of the recorded data. Here it can be seen that the series of high-amplide, high-frequency content event are all surface related multiples. After an estimate has been made of all the different types of surface related multipes, the multiples have been subtracted by a simultaneous adaptive least-squares subtraction method (see Verschuur and Berkhout, 1997). This multiple elimination procedure estimates also the (inverse of the) source wavelet per shot record. However, this will not be discussed in this paper. The resulting shot gathers are depicted in Figure 1 on the right hand side. Here it should be observed that there are still some remaining multiples in the larger offsets. These multiples appearing in the larger offsets may be suppressed using Radon-based methodologies. However this appears not being necessary, since the effect of these remaining multiples will be stacked out in the final stack. Note that in the resulting shot gathers, the strong near offset and high-frequency content multiples have been suppressed and some possible low-frequency subbasalt primaries have become better visible.

The data before and after multiple suppression has been stacked and the results for the considered line are shown in Figure 2. The upper picture shows the stack of the original data (with all surface related multiples included). The middle pictures shows the stack of the estimated multiples only and the lower picture shows the stack of the multiple suppressed data. Note that in this figure, only the upper part of the section is shown (upto 4 seconds). It can be noticed that in the lower section the strong and high-frequency content multiples have been suppressed and some possible low-frequency subbasalt primaries have become better visible.

Note that the first order surface related seafloor multiples are cutting through the primaries at both sides of the section. This can be better viewed in the blown-up versions, as shown in Figure 3a, showing only the left part of the line upto 3.5 seconds. The white arrows indicate the different events that have been suppressed by surface related multiple removal. Note that in the original data the strong multiples are cutting through the primary reflections. Comparison of the 3 blow-ups, shows clearly that the data has been cleaned up in the resulting section and that most high-amplitude, high-frequency multiples have been suppressed. Apart from the fact, that a very poor SNR signal is recorded related to the subbasalt structures, the surface of the basalt layer is very rough and the subsurface contains a tremendeous amount of faulting structures. These will create a series of strong diffractions which add to the complexity of the recorded waves. From the resulting section (after surface related multiple elimination, see Figure 2, bottom picture) the top of the basalt has been interpreted and flattened. The result of this flattening is shown in Figure 3b. This alignment of the top of the basalt may show a better continuity of the subbasalt structures. Note the lower frequency content in the structures below the flattened horizon. The horizontal line representing the alignment of the topbasalt, shows clearly the transfer of high-amplitude and high-frequency signal into low-amplitude and low-frequency signal.

Conclusions and Discussion

The successful application of multiple suppression has been demonstrated on a marine line recorded offshore of the volcanic Faroe islands. The mixture of basalt layers with surroundings sediments in this particular area has created a complex geology which makes it extremely difficult to image and interpret subbasalt structures. Within this area, many waves will be refracted because of the inter-laying basalt layer and will create poor SNR signals related to the subbasalt structures. The data shown in this paper contained some very strong high-amplitude and high-frequency content multiples which have been successfully estimated and suppressed from the data. After applying the surface multiple suppression to the 6 km offset shots, it appeared that in this particular area, the strongest multiples are concentrated in the first 2 km offsets. Once these surface related multiples have been suppressed from the data, new opporunities have been created for aiming towards imaging beneath basalt. The primaries below the basalt are of extremely low amplitude and frequency. New velocity analysis and full redatuming of the wave field from the surface towards the topbasalt layer may simplify the “prestack” identification of subbasalt refelcted events. Alignment of the topbasalt layer may assist in identifying “poststack” structures beneath the basalt.

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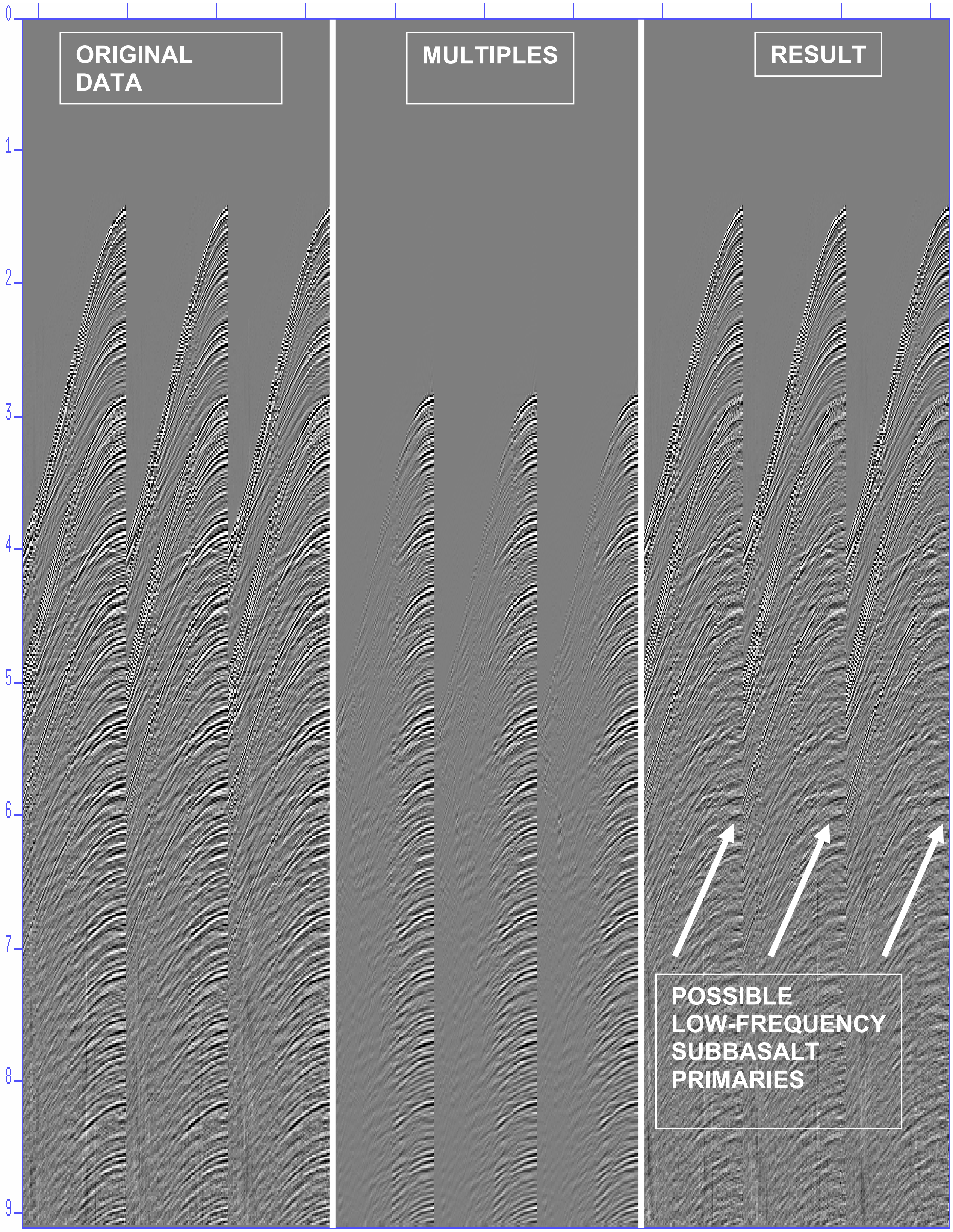


Figure 1: Illustration of the result of surface related multiple removal procedure on three prestack shot gathers. Note that in the resulting shot gathers, the strong near offset and high-frequency content multiples have been suppressed and some possible low-frequency subbasalt primaries have become better visible.

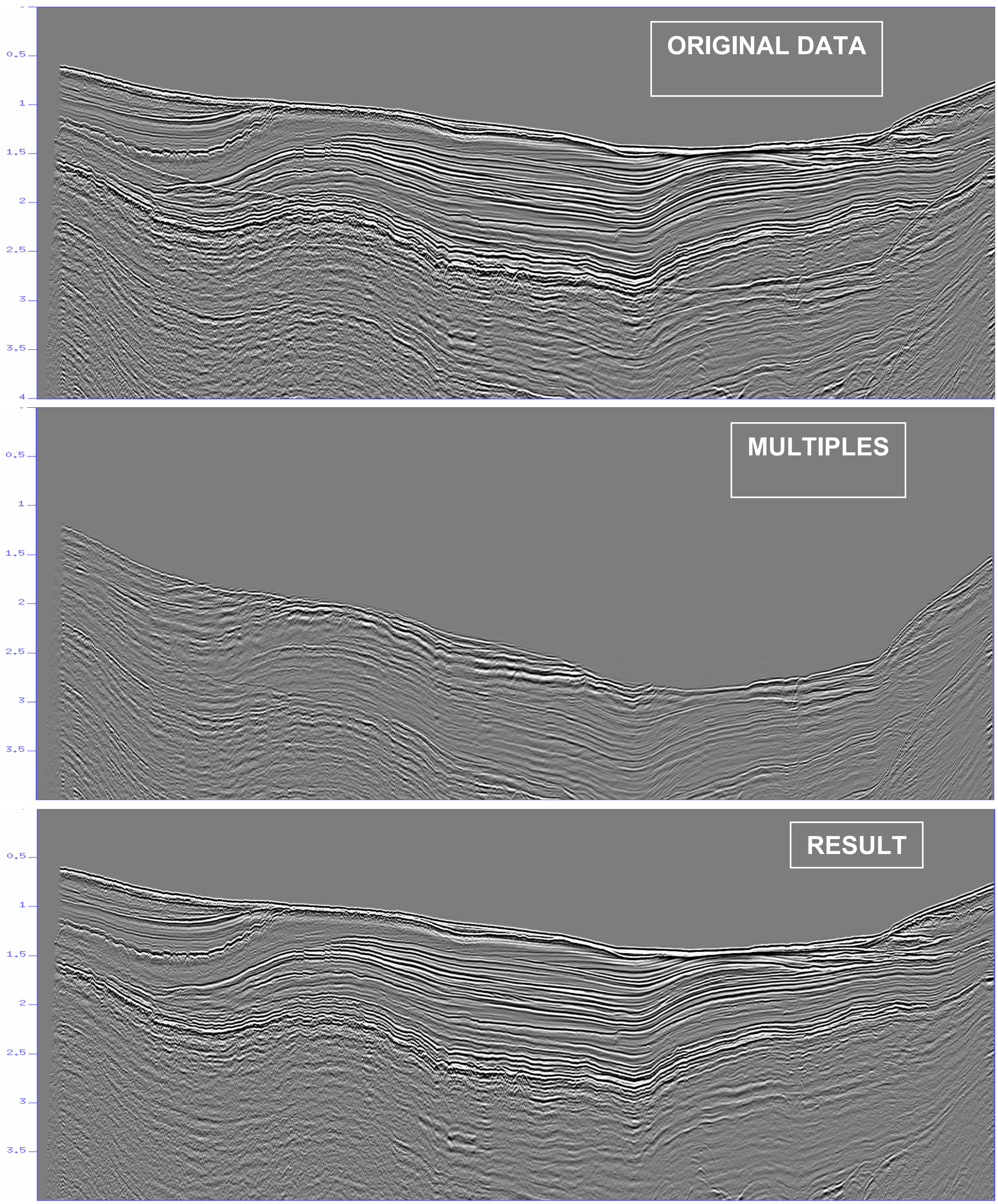
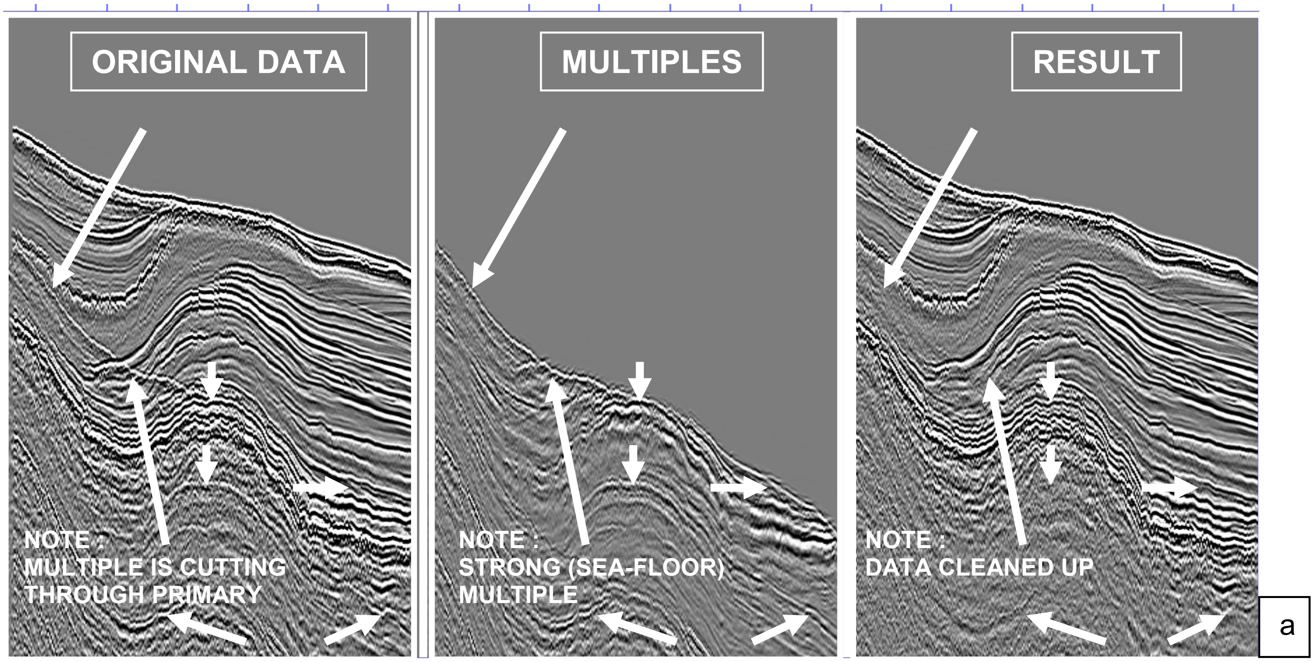


Figure 2: Illustration of the result of surface related multiple removal procedure on poststack section along a line (only upper part shown here, upto 4 seconds). Note that in the resulting section, the strong and high-frequency content multiples have been suppressed and some possible low-frequency subbasalt primaries have become better visible.



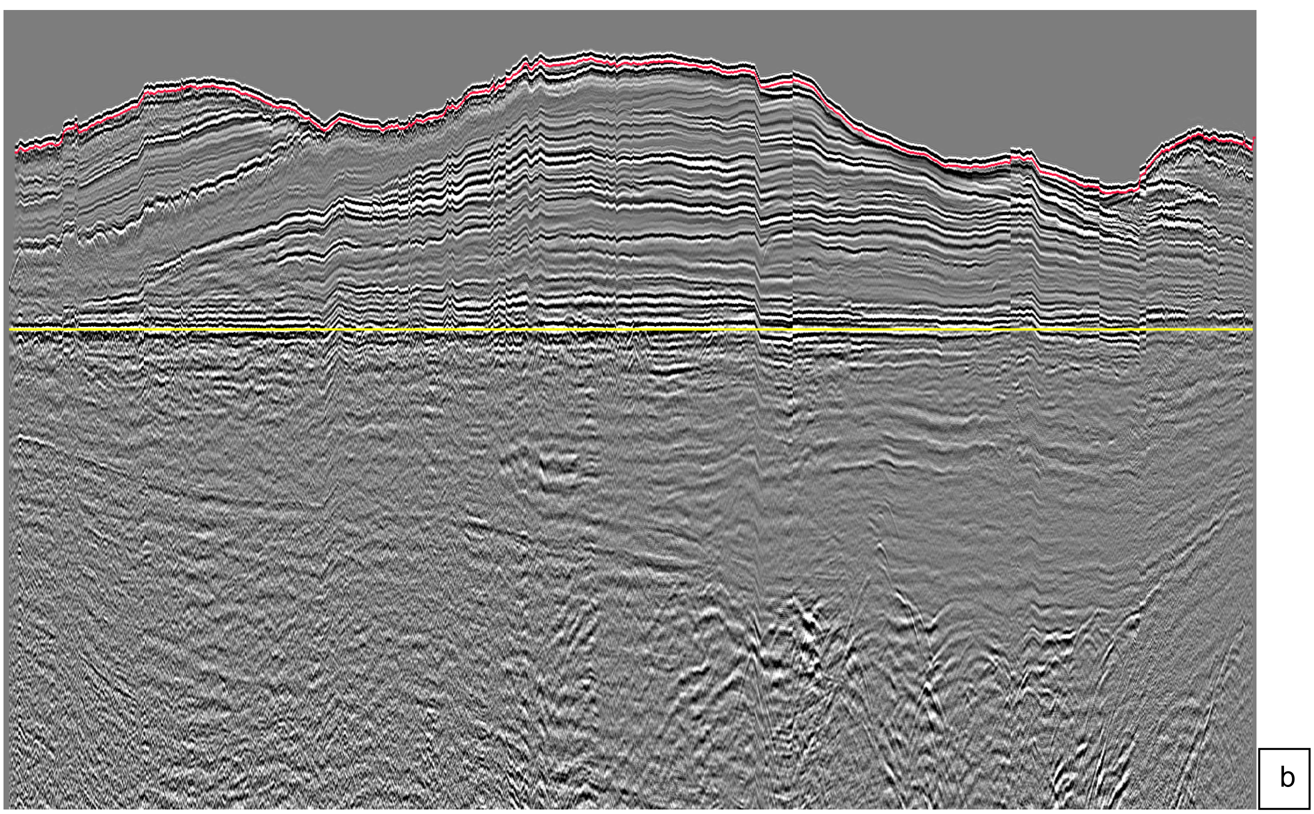


Figure 3: a)Blow up of a part of the section. The white arrows indicate the different events that have been suppressed by surface related multiple removal. Note that in the original data the strong multiples are cutting through the primary reflections. b)The resulting section (Figure 2) is flattened along top basalt layer. Since the surface of top basalt layer is very rough in structure, this alignment will show a better continuity of the subbasalt structures. Note the lower frequency content in the events below the flattened horizon.