Optimum seismic processing of modeled outcrop data from Van Keulenfjord, Svalbard.

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Summary

Synthetic seismic data from *an integrated outcrop study* offer unique possibilities for detailed studies of how seismic processing affects the data, and thereby the seismic interpretation results. The modeled outcrops in this study are located on the northern side of Van Keulenfjord, Svalbard, in the Norwegian arctic. The synthetic data, produced by an elastic finite difference modeling scheme, show that many unexplained false reflections, not related to the geologic model, are present on the initially processed section. These reflections would have been very difficult to distinguish from real reflections without the knowledge of the geological model. Previous seismic processing attempts have been unsuccessful in eliminating these false events. This is partly due to the fact that the mechanisms behind the false reflections have not been known. Interpretation of NMO velocities and snapshots of wavefield propagation show that the false reflections in the synthetic data most likely are a combination of water bottom multiples of deeper reflections and P-S converted waves. The P-S converted waves are not visible on the original seismic section due to the high amplitudes of the multiple reflections. The processing results show that predictive deconvolution, f-k demultiple and parabolic Radon filtering are ineffective for attenuation of reflected water bottom multiples as they occur in the present dataset, while predictive deconvolution applied in the z-p domain was effective for suppressing multiples for all offsets. The following processing scheme was selected: first predictive deconvolution in the 2-p domain to eliminate multiples, followed by parabolic Radon transform to attenuate the P-S converted waves.

Introduction

The cliffs along the fjords in Svalbard, in the Norwegian arctic, are very well suited for geological studies, and traditional field studies have been carried out for more than hundred years in this area. In the recent years a new type of outcrop based studies has also been carried out along these excellent exposures. Several *integrated outcrop studies* have been carried out on large scale outcrops in Svalbard (Johansen et al., 1994, Helland-Hansen et al., 1994 and Johansen et *al.,* in press). An *integrated outcrop study* (IOS) produces both geological and geophysical data based on the outcrops. A typical IOS-procedure, as described by Johansen et al. (in press) consists of: (1) traditional geological fieldwork (2) photogrammetry (3) petrophysical analysis (4) seismic modeling (5) seismic processing (6) geological and geophysical interpretation.

In previous studies geophysical IOS-data have been used to solve pure seismic imaging problems, particularly in complicated geological settings. Previously published IOS-data were produced by raytracing, and processing of the data were not necessary. Here we use seismic IOS-data modeled by an elastic finite difference modeling scheme, subsequently processed by conventional processing procedures. Such IOS-data offer an unique possibility for detailed studies of how seismic processing affects the data.

The modeled outcrops are located on the northern side of Van Keulenfjord, Svalbard, and the seismic IOS-data were produced by Johansen et al. (in press). The synthetic data show that many unexplained false reflections, not related to the geologic model, are present on the initially processed stack sections. These reflections would not have been identified as false reflections without the knowledge of the geological model. Many previous seismic processing attempts have been unsuccessful in eliminating these false events. This is partly due to the fact that the mechanisms behind these false reflections have not been known. We here present a strategy for identification and explanation of the false events and propose an effective processing sequence for attenuating the events.

Modeling

The synthetic data were produced by an IOS-procedure as briefly described above, and in more detail in Johansen et al. (in press). The geological model is approximately 19 km long (Fig. 1). The main formations compose an overall progradational package dominated by six facies associations including coastal plain-, delta front-, delta slope-, turbidite- and offshore marine shale facies. For more details on the geological model see Mellere et al. (in press). To make the model even more realistic an overburden of 1.1 - 1.4 km thickness was added on top of the Svalbard model. The details of the overburden model were taken from North Sea wells. To simulate marine seismic, a water layer of l00-200 m was added on top of the combined model. This final model consists of elastic and isotropic layers. A 2D elastic finite difference program (Mittet et al., 1988) was used to perform the seismic modeling. The modeled data have a gridded resolution of 2x2 m. The data were then processed by several commercial contractors. The final processing result from on of these contractors is shown in Figure 2.

Identification of false reflections

What is causing the false events? Since we have performed a 2D seismic modeling, possibilities for sideswipes can be ignored. Other probable causes for the events are multiples and shear-wave converted waves. The causes of these events were identified by two methods: velocity analysis and analysis of snapshots of the wavefield. The false events show a lower stacking velocity than the primaries above and below. In addition the amplitudes of the false events at or near zero offset are relatively high. This implies that we have multiple energy since little shear wave conversion occurs for small offsets. From the velocity analysis alone it is not possible to distinguish internal multiples from water bottom multiples. Therefore we also performed an interpretation of seismic snapshots from the seismic modeling. Snapshots of the wavefield calculated for both vertical and horizontal components of displacements were used for identification of false events. From the snapshots we identified the multiples as being 1. order water bottom multiples reflected from strong acoustic interfaces deeper in the geological model. In addition the snapshots also revealed a P-S converted wave arriving at the same time as the multiples. This event was not visible on the stack section due to the dominating amplitude of the water bottom multiples.

Discussion of seismic processing

The initial processing of the synthetic data (Fig. 2) emphasized on seismic resolution and multiple attenuation. Techniques which were used for multiple removal were: wave equation multiple rejection, predictive deconvolution, parabolic Radon filtering and f-k demultiple filtering. In addition, inner trace mute was also tested for elimination of relatively strong amplitude reverberations at near offsets. Most of the available multiple suppression techniques are mainly based either on NMO differential or on the predictive properties of the multiples.

In order to propose an optimum processing sequence for attenuating the false events it is useful to know why all the listed techniques failed. Wave equation multiple rejection uses wavefield extrapolation of shot records to eliminate water bottom related multiples and subtract them from the records (Berryhill and Kim, 1986). This process works best for a flat to moderately dipping water bottom. Simple water bottom multiples are expected to be eliminated while water bottom multiples from deeper reflections are reduced but not eliminated.

Predictive deconvolution relies on the predictive nature of multiples for their elimination. Results of predictive deconvolution with prediction gap of 24 ms and operator length of 240 ms applied to two CMP gathers in our data show that multiple reflections were eliminated only for the near traces. This is mainly because the multiple period cannot be considered as constant in a CMP gather. This is most pronounced for shallow events and large offsets (Hatton et al., 1986).

Parabolic Radon transformation is used for suppression of multiples relying on their NMO differential. The technique normally used is modeling of the multiples and subtraction from the input seismic data. The Radon transform distinguishes between primaries and multiples based on residual moveout from near to far offset (Hampson, 1986). From our data we see that this technique is effective for far traces where the normal moveout is large. For small offsets this technique is not effective. The f-k demultiple filter also shows good multiple suppression for the far traces but poor suppression on the near traces.

According to Taner (1980) multiple periods are fixed for a radial trace or for each r trace on a slant-stack'gather (τ-ρ domain). He applied predictive deconvolution along radial traces to eliminate long period multiples. This method was tested since it was realized that the other methods only work for restricted parts of the CMP. After applying this processing to our data most of the false events were gone. A close look at the data now revealed a P-S converted event which was not visible on the previous stack section because of the presence of the stronger water bottom multiple reflections. The P-S converted event will not be eliminated by predictive deconvolution since it is not periodic like multiples. However, the P-S converted reflection can be separated from the primary reflections by its lower NMO velocity. In addition the event occurs only on large offset traces and can be eliminated by applying parabolic radon filtering or f-k filtering. Figure 3 shows the stacked section after removal of both the multiples and the converted waves.

Conclusions

Seismic modeling of the large scale outcrops has provided unique possibilities for testing different processing schemes and allows seismic interpreters the excellent opportunity to evaluate the processing quality.

Interpretation of NMO velocities and snapshots of wavefield propagation show that false reflections in the synthetic data most likely are water bottom multiple reflections and P-S converted waves. The P-S converted waves are not visible on the original seismic section due to high amplitudes of multiple reflections.

The processing results show that predictive deconvolution, f-k demultiple and Radon filtering are not effective for attenuation of reflected water bottom multiples as they occur in the present dataset, while predictive deconvolution applied in the τ-ρ domain was effective for suppressing multiples for all offsets.

For our data we suggest the following processing scheme to eliminate multiples and P-S converted waves: first predictive deconvolution on τ-ρ data, followed by parabolic radon transform to attenuate the P-S converted waves.

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Figures

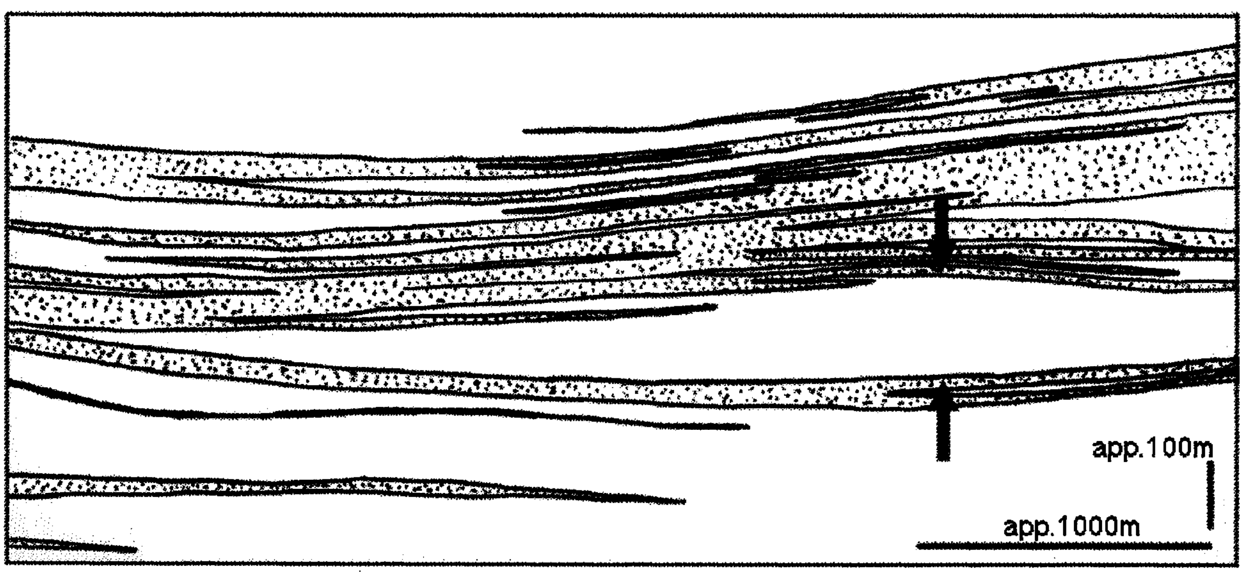

Fig. 1 A simplified geological model of a portion of the studied outcrops in Van Keulenfjord, Svalbard. The model was constructed based on photogrammetry and traditional field work. The darker parts of the model are mainly sandstones, while thus lighter areas represent fine gained sedimentary strata. Prior to seismic modeling an impedance model was constructed based on velocity- (Vp,Vs) and density measurements of rock samples collected in the outcrop.

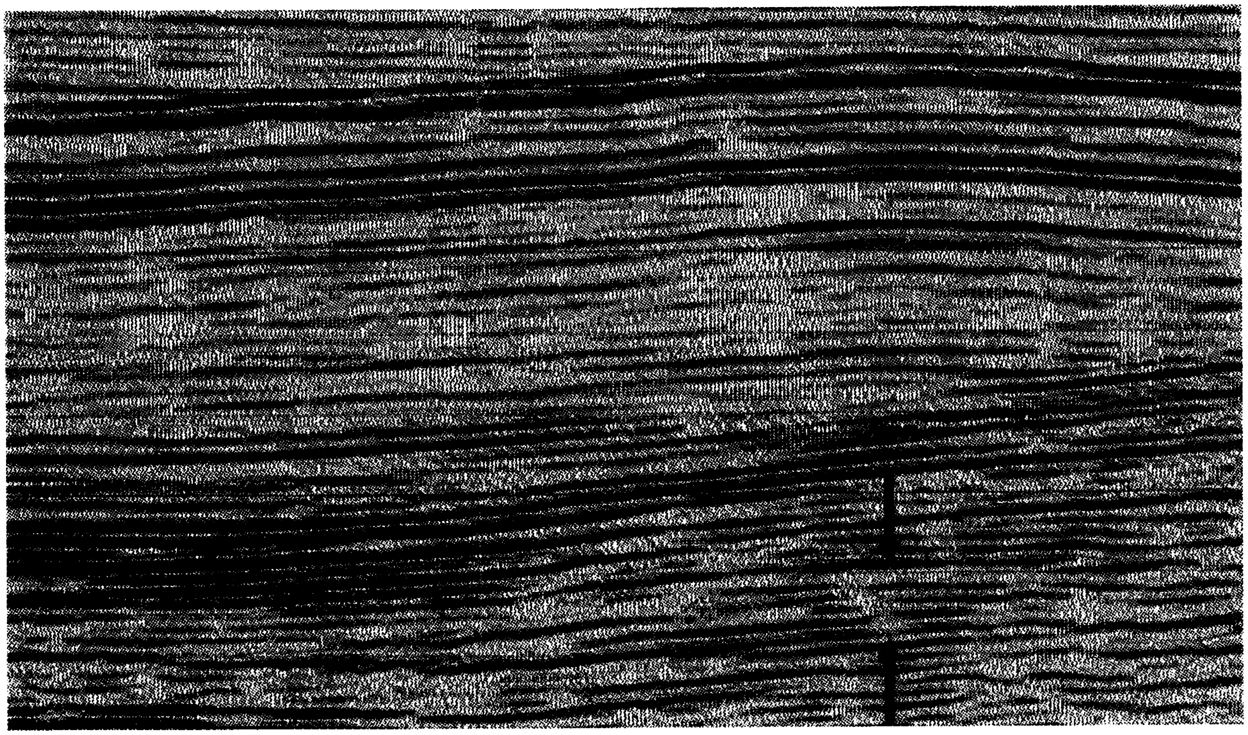

Fig. 2 Modeled seismic section processed by an external contractor. The information normally available to the contractor when processing real marine seismic data, was also given to the contractor in this case. The length of the seismic image corresponds to Fig. 1, and the vertical scale is 5 cm/sec TWT. Note that false events are present in the data. Here we focus on the events in the interval between the arrows. This interval corresponds to the homogenous layer between the arrows in Fig. 1, and we see from the geological model that real reflections should not occur within this interval.

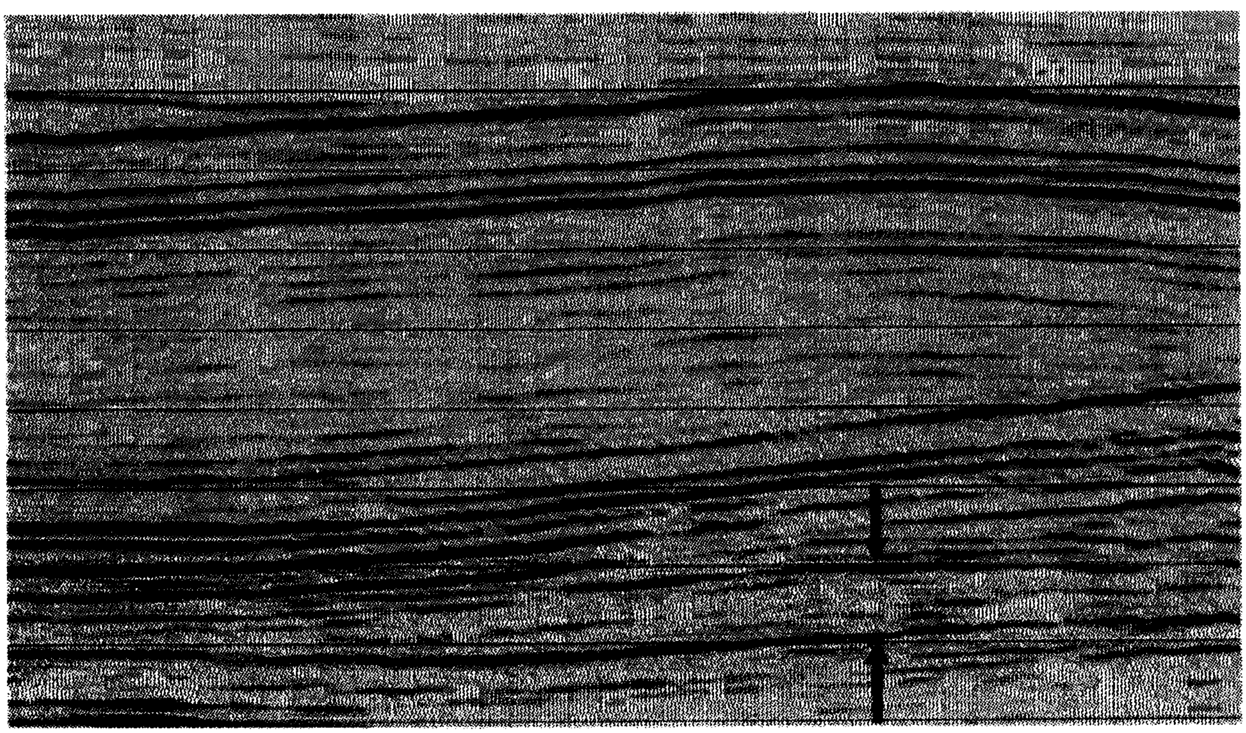

Fig. 3 Modeled seismic section processed by the processing flow recommended by this study. All information about the geological model was available during the test processing. The length of the seismic image corresponds to Fig. 1, and the vertical scale is 5 cm/sec TWT. The interval between the arrows corresponds to the interval marked by arrows in Fig. 1 and Fig. 2. In Fig. 3 the marked interval appears more or less reflection free as should be expected when comparing with the geological model in Fig. 1