Modelling complex near-surface features to improve shallow seismic exploration.

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SUMMARY

Land seismic exploration is often limited or impacted by complex structures in the near surface. These can include large variations in velocities related to weathering (low velocity) or basalts (potentially high velocity).

Timing changes due to near-surface velocity variations are often accommodated by applying statics corrections during seismic processing. Shallow coal exploration requires high-resolution data to image structures and faulting. A good understanding of these features is required for both safety and economic reasons. However, in some cases small errors in statics correction may have a significant impact on the viability of the use of seismic data in these complex environments.

Often near-surface structures also show non-planar characteristics which may attenuate or further complicated the seismic response.

In this paper we use finite-difference visco-elastic modelling to investigate the impact that a number of common near-surface structures have on seismic data. This modelling has been used to determine the optimal acquisition and processing parameters required for a seismic program in order to achieve desired results.

Key words: Seismic reflection, modelling, near surface.

INTRODUCTION

The structure of the near-surface environment can be quite complex. This can include large variations in both velocity and density. For exploration seismology we generally want to image reflections at depths below these surface layers. However, adverse near-surface conditions have the potential to significantly degrade the target seismic reflections.

In the coal industry, particularly in the Bowen basin, there are often near-surface basalt structures overlying economic targets. As has been previously demonstrated (e.g. Zhou et. al., 2010) these can often cause a reduction in the signal-to-noise content of the seismic reflections from the deeper coal seams. Figure 1 compares two shot records from a location in the Bowen basin. These records are in close proximity, demonstrating that significant variation can occur over relatively short distances.

In areas where these types of structures are likely to occur it is often prudent to employ shot-record modelling techniques (e.g. Battig and Hearn, 2001; Sun et. al. 2010) prior to conducting a seismic survey. Modelling methods can be used to determine the optimal acquisition and processing design.

METHOD AND RESULTS

In this investigation I have used visco-elastic finite difference modelling (Robertsson et. al., 1994) to generate seismic records for a number of geological structures of increasing complexity. Representative examples are presented here.

Figure 2 illustrates a typical coal environment with a simple weathering layer. Often this sort of model may be used in the initial design phase of a seismic survey. It includes multiple coal seams of typical thicknesses and includes a fault of likely size. The seismic record shows refractions, reflections (below .1s), ground roll and noise. The ground roll is dispersive but is generally a lot simpler than usually observed on field records (e.g. Figure 1). The stacked section clearly indicates the coal seams and generally looks more 'synthetic' than a true field record would be expected to appear.

In an attempt to develop a more realistic seismic record I have examined a number of different weathering variations. These include high velocity weathering, variable depth weathering, multi-layer weathering and combinations of these. Figure 3 presents a more advanced example of this process. This figure shows the results from a model consisting of a weathering with a slow background velocity, and with eight high velocity layers. The high-velocity layers are thin and rough. This character was inspired by examination of bore-hole logs in the vicinity of the records in Figure 1.

The shot record in Figure 3 has much stronger ground roll than that in Figure 2 and the seismic reflections are almost impossible to observe. This more closely agrees with what is commonly observed on field records acquired over complex basalts. The stacked section in Figure 3 indicates that the correct processing sequence can allow the coal seams to be identified. However, this section is much noisier, and fault interpretation would be much more difficult.

This modelling suggest that there is potential to identify coal seams on stacked data even when the near-surface complexities make it difficult to see reflectors on records.

These models have provided a useful initial understanding. However, they are likely to still be simpler than real geology. To construct a more realistic model (Figure 4), I have used geophysical borehole logs corresponding to a location within the Bowen basin.

The geological model in Figure 4 includes the borehole locations (green dotted lines), with black lines indicating boreholes in which basalt has been found. Note that the holes with basalt often have quite low near-surface velocities. An examination of these boreholes suggests that they include interbedded high and low velocity zones. The modelled seismic record suggests that most of the signal of the seismic reflection is swamped within the ground roll cone. However, some reflection energy is visible on the far offsets. The stacked section is quite noisy. If the target reflector was the shallowest seam it is likely that the seismic survey parameters would be adequate to image the data. However, if information about the deeper seams is required than alternate options such as a deep drilled dynamite survey may be required. This is especially true near boreholes that contain basalt.

CONCLUSIONS

This investigation has demonstrated that arbitrarily complex geological models can be developed, with corresponding synthetics showing many features observed at real survey sites. Realism can be improved by incorporation of real borehole-log information. These model data can be used to understand the possible limits on future seismic exploration, and to ensure that such surveys are acquired in an efficient and cost-effective manner.

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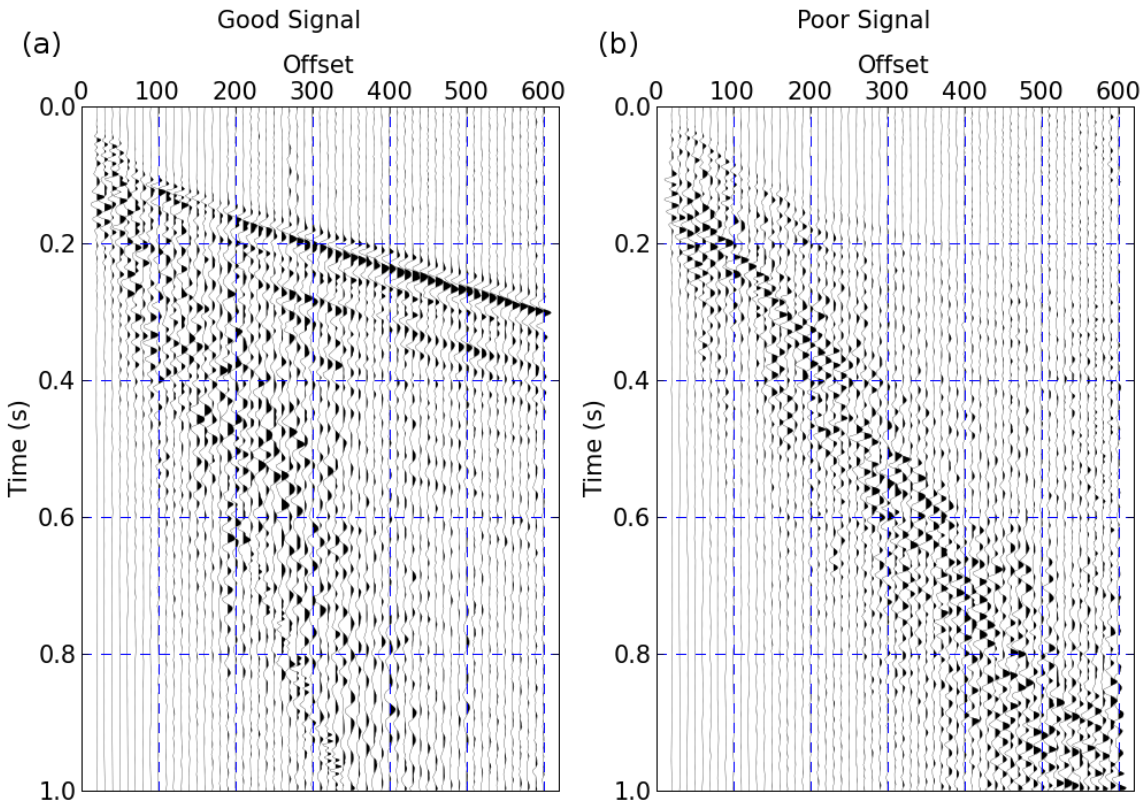

Figure 1: Seismic records from the same area with varying weathering characteristics. (a) good data quality with relatively simple weathering. (b) poor data quality due to complex weathering.

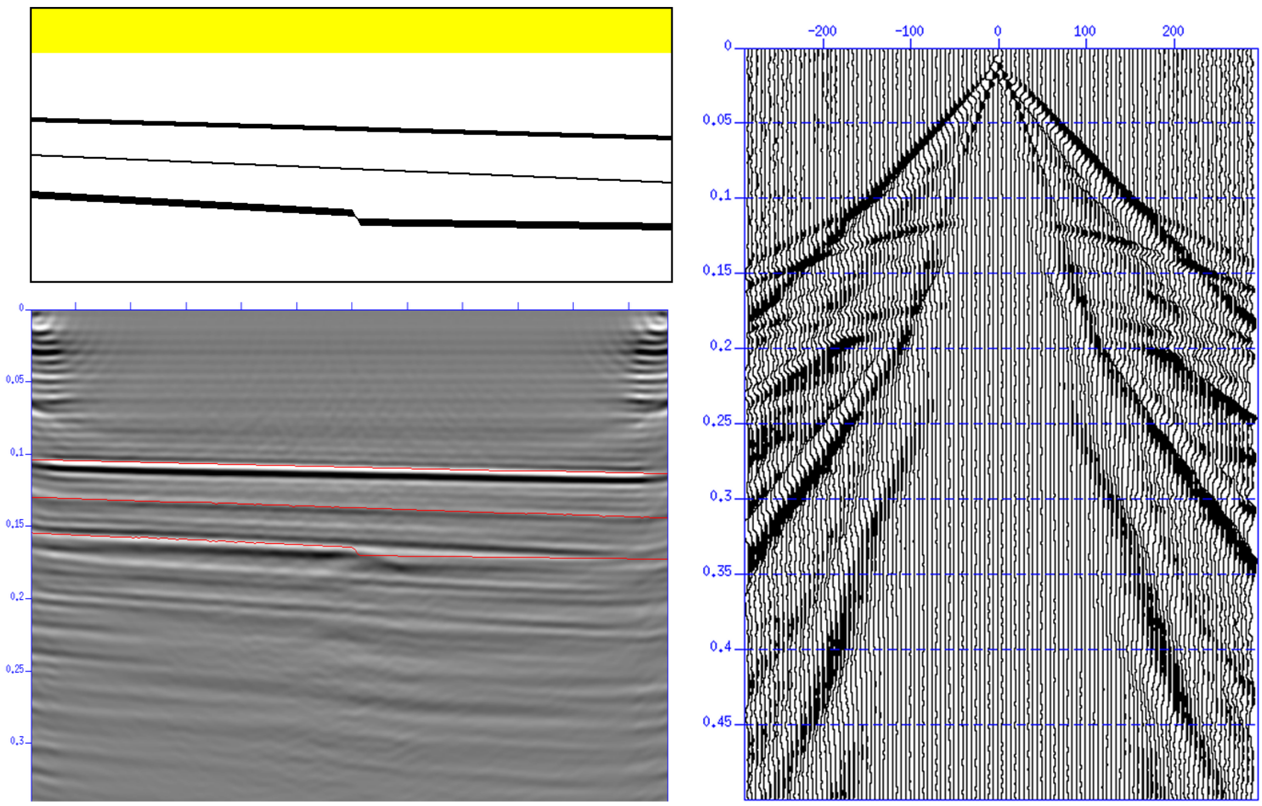

Figure 2: Three layer coal model with simple weathering. (Top Left) Geological model. (Right) Shot record generated using visco-elastic finite-difference modelling. (Bottom Right). 2D stacked section created by processing the modelled shot records.

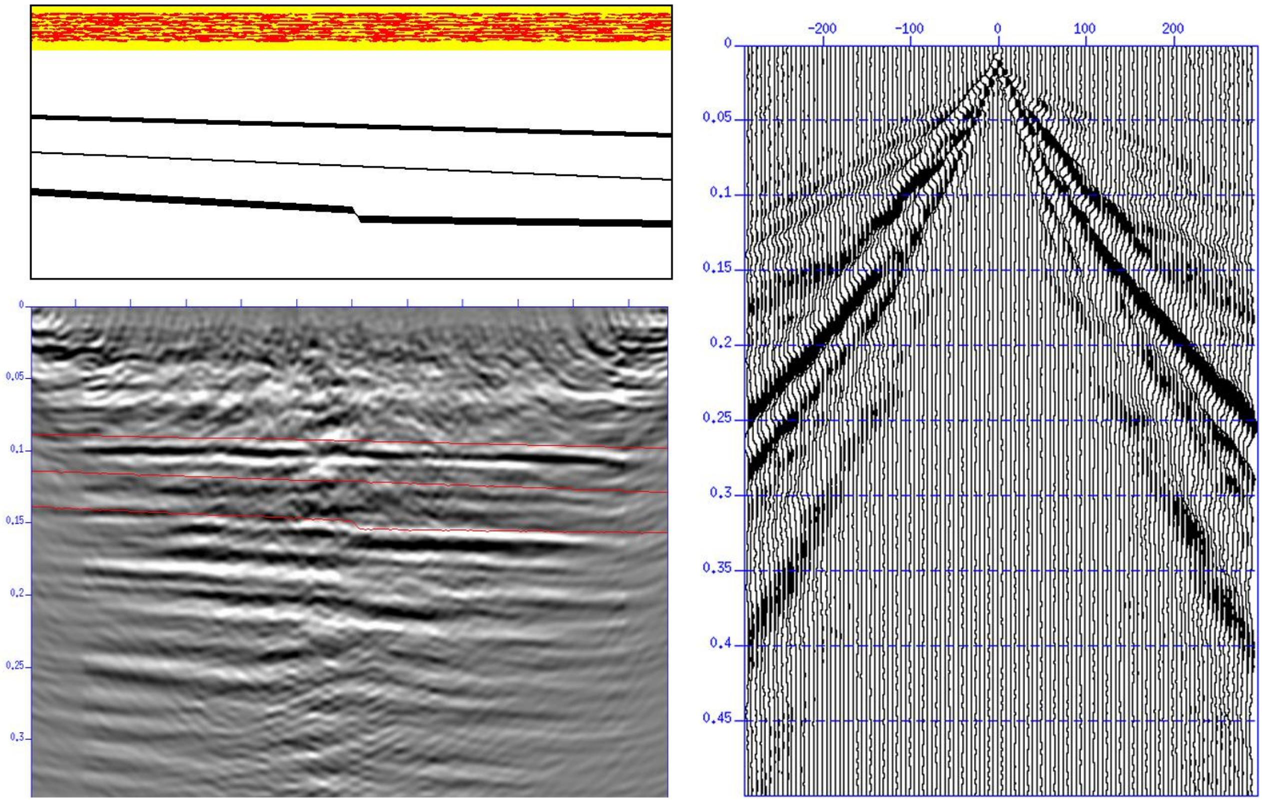

Figure 3: Three layer coal-model with complex weathering. (Top Left) Geological model. (Right) Shot record generated using visco-elastic finite-difference modelling. (Bottom Left) 2D stacked section created by processing the modelled shot records. The increased complexity in the model results in much more realistic data.

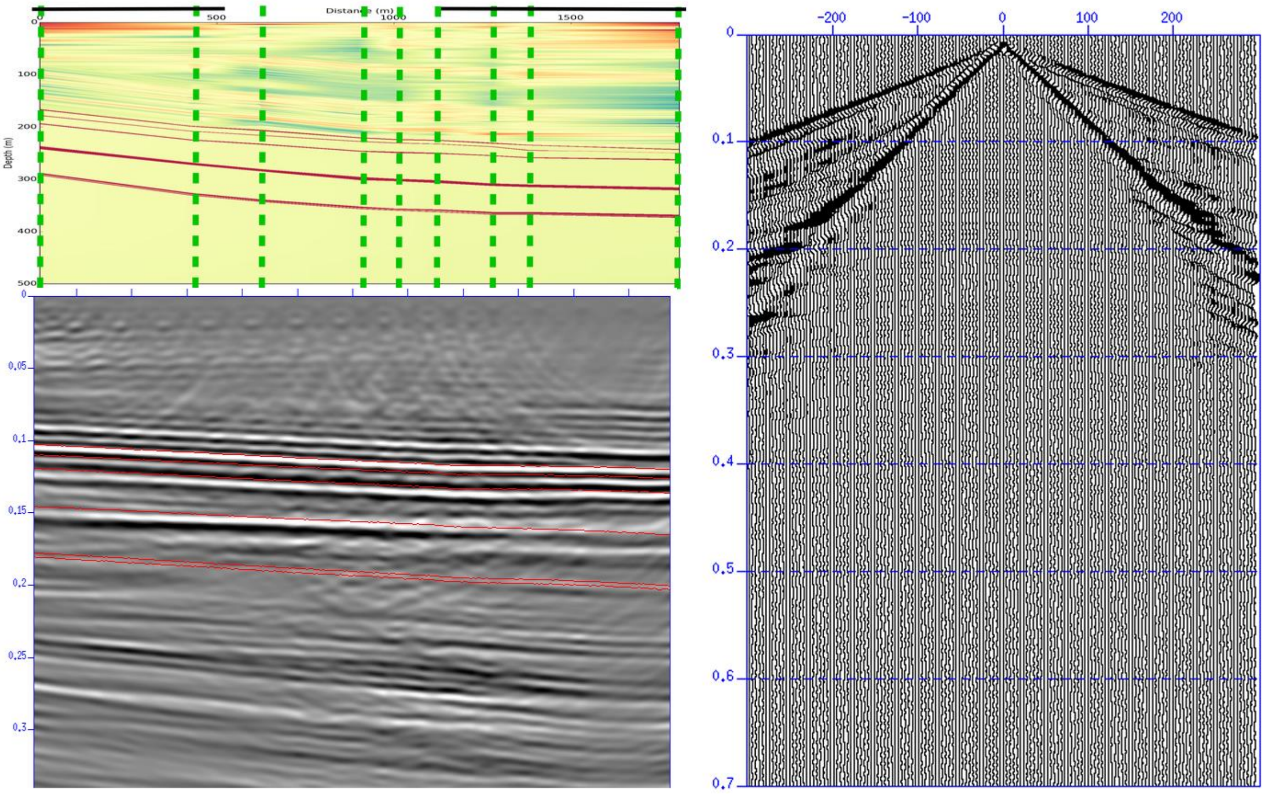

Figure 4: Three multi-layer coal-model with borehole derived weathering. (Top Left) Geological model (Low V: Red – Yellow – Green – Blue :High V). (Right) Shot record generated using visco-elastic finite-difference modelling. (Bottom Right). 2D stacked section created by processing the modelled shot records.