Pre-Processing Considerations for Reverse Time Migration

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Summary

Almost all conventional pre-processing is conceived of with one-way wave propagation in-mind. If we take into account the existence of two-way wave propagation arrival events, then many of the underlying assumptions of moveout behavior implicit in some pre-processing techniques must be re-evaluated.

Using 2D synthetic data, we demonstrate that the moveout behavior of double bounce arrivals (a class of two-way propagating events) can be compromised by pre-processing designed to remove events exhibiting 'anomalous' moveout behavior .

These observations are of interest to us, as we are now beginning to employ two-way migration schemes to image complex structures. However, if we continue to use conventional pre-processing techniques, we run the risk of removing the very events we are trying to image.

The observations made on the basis of synthetic modeled data, are extended in this work to real data examples, all from the North Sea, where in the central graben, we commonly have steep piercement salt diapir structures, which are good candidates for producing useful double bounce arrivals, which can be imaged using RTM.

Introduction

The speed and cost effectiveness of contemporary computer systems now permits us to implement more general algorithmic solutions of the wave equation (Whitmore, 1983, Baysal et al, 1983, McMechan, 1984, Bednar et al 2003, Yoon et al 2003, Shan & Biondi 2004, Zhou et al, 2006, Zhang et al, 2006). The restriction to one-way propagation can be lifted, and data migrated so as to take advantage of more esoteric propagation paths, such as turned rays, double bounce arrivals, and potentially multiples (Mittet, 2006).

However, in order to take advantage of these improved algorithms, we must ensure that the data input to migration have not been compromised in any way. Specifically, in this work we address the moveout behavior of double bounce events (Hawkins et al, 1995, Bernitsas et al, 1997, Cavalca & Lailly, 2005), and note how many conventional pre-processing algorithms can damage these arrivals, thus rendering some aspects of any subsequent high-end migration superfluous.

We commence our analysis by reviewing the conclusions of some preliminary work studying synthetic data (Jones, 2008a), showing the moveout behavior of some simple double bounce events (also referred to as 'prism waves' by some authors). For ease of demonstration, we firstly employ a ray-trace package, with which we can model individual selected arrivals, and later create more complex synthetic data using an elastic finite difference (FD) package. After investigating the moveout behavior of the simple models, we move-on to a model representing a complex North Sea salt dome structure (Davison, et al 2000, Thomson, 2004; Farmer, et al 2006). We show the effect of various conventional pre-processing steps on double bounce arrivals, and carry these analyses trough to migration with an 2D RTM algorithm capable of imaging the double bounce arrivals.

We then extend this analysis and demonstration-of-principle from the 2D synthetic data to real data (Jones, 2008b), were we see similar classes of event, and the same degradation of double bounce arrivals shown in the synthetic trials.

The Modeling

We commence by looking at four simple scenarios: a simple right-angle corner reflector; an acute angle reflector (non-crossing rays); an acute angle reflector (crossing rays), and turning rays (Hale et al 1992). For obtuse angle geometry, we don't have double bounce arrivals for this layout: we would need extremely long offsets and large arrival times.

We will commence with discussion of these scenarios, and it will become clear that the moveout behavior they exhibit does not conform to what we expect for 'normal' one-way arrivals paths, but more closely resembles events such as those resulting from scattered energy or diffracted multiples. We know that for simple quasi-1D cylindrical models that all co-axially recorded events in a CMP gather will appear with their apex at zero offset. It is this observation that guides the design principle of various multiple suppression techniques and the justification to muting in Tau-P space to suppress backscattered energy.

We then look at a full synthetic data set created along a 2D crestal line of the 3D production model representing our North Sea example, and show the effects of various pre-processing techniques on these data. For the geometry here, we have: a single bounce at the flat-lying part of a reflector; a single bounce at the dipping part of this reflector; a non-crossing double bounce involving the flat and dipping reflectors; a crossing double bounce involving the flat and dipping reflectors (not shown in figure 1, so as to avoid clutter); ray paths passing into the salt, with an internal reflection at the steep salt wall, and a second bounce outside the salt from the flat or steep reflectors (not considered here, as they have relatively low amplitude due to the transmission coefficients at the salt wall).

These ray paths and an associated CMP gather are shown in figures 1 & 2. We can clearly see from the ray-tracing exercises, which are the single and which are the double bounce events illuminating the salt flank. The velocity model shown is based on a 2D crestal line taken from an actual 3D North Sea example (Farmer, et al 2006). The production project in that case was anisotropic using VTI 3D RTM code, but for simplicity, here we are using 2D isotropic modeling and 2D isotropic RTM.

Pre-Processing

Essentially, we are looking at processes that eliminate events which exhibit ‘anomalous’ moveout behavior in the CMP domain. For conventional 2D geometry, such events (in a one-way wave propagation paradigm) constitute diffracted multiples and scattered energy. In other words, events that appear to have secondary source locations from a one-way perspective. Such events are classes of two-way wave propagation, in that the ray-path changes direction before (or after) its ‘main’ reflection from the interface of interest.

We commenced by assessing Radon demultiple. If we were to employ the Radon filter to directly output the multiple free ‘primaries’, then we would have a problem, as all apex-shifted events would be corrupted, appearing as a smeared artefact in the output. However, this issue can be circumvented if we use the Radon to model the multiples, and then adaptively subtract these from the input data. Working in this way, we would preserve the apex-shifted arrivals in the CMP gather. Consequently, we do not show the Radon results here.

We then assessed an apex shifted multiple attenuation routine - designed to attenuate events whose apexes are shifted from zero offset in CMP gathers: a first order approximation to 3D SRME. By design, this effectively eradicates the double bounce events. Lastly, we assessed a Tau-P mute (for backscattered noise).

We show the effects of these processing sequences in the following figures, for a set of CMP gathers straddling the salt dome. Figure 3 shows the raw input FD modeled data, whilst figure 4 shows the output from ASMA plus Tau-P muting. Apex shifted events are ‘successfully’ attenuated. This would be considered a good thing for conventional processing, but is deleterious for two-way imaging.

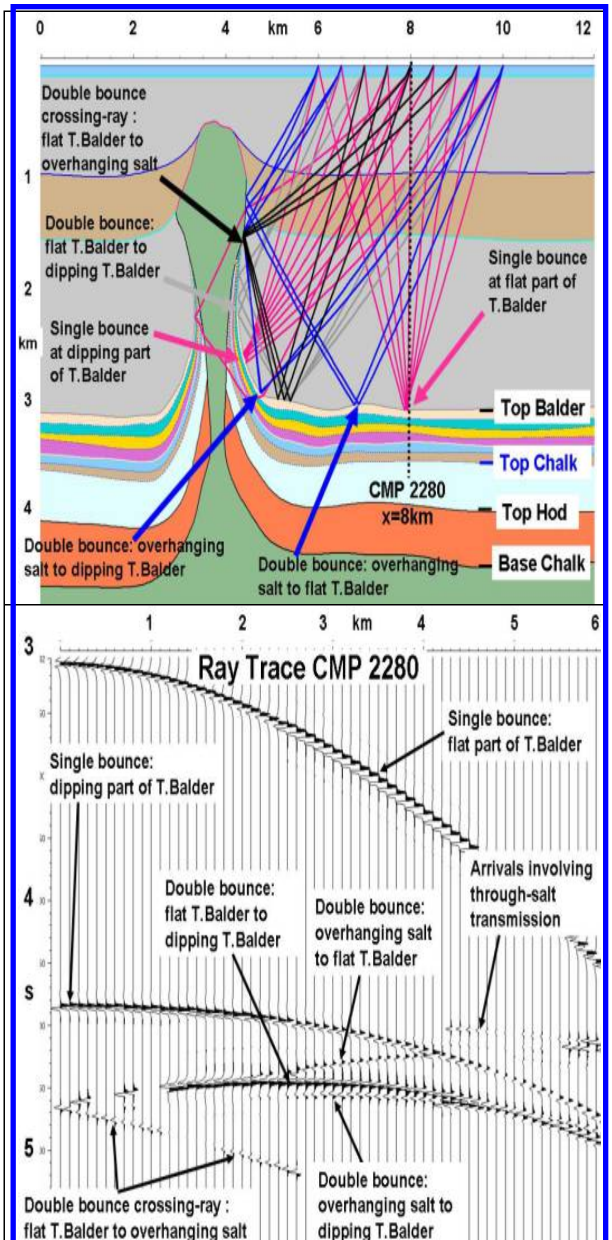
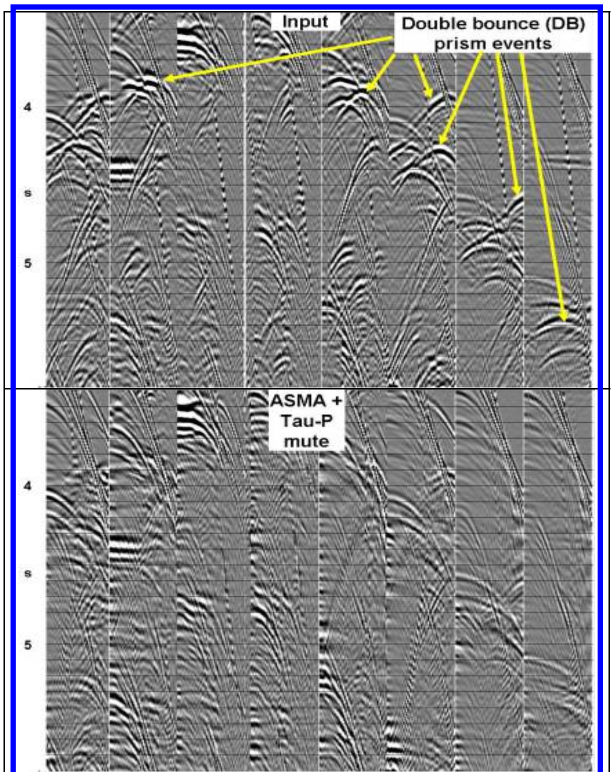


Figure 1 (top), plot of a few sparse rays shown against the interval velocity model. The absence of a strong sediment gradient precludes turning rays in the sediments, although a strong compaction velocity gradient below the Top Balder and top Chalk does produce turning rays. A single CMP gather (from the surface location at 8km) is shown in figure 2 (bottom).



Figures 3 (top) & 4 (bottom): selection of CMP gathers from the FD modeled data, showing the raw input, and the output from an Apex Shifted Multiple Attenuation scheme (ASMA) plus Tau-P muting. Apex shifted events are ‘successfully’ attenuated.

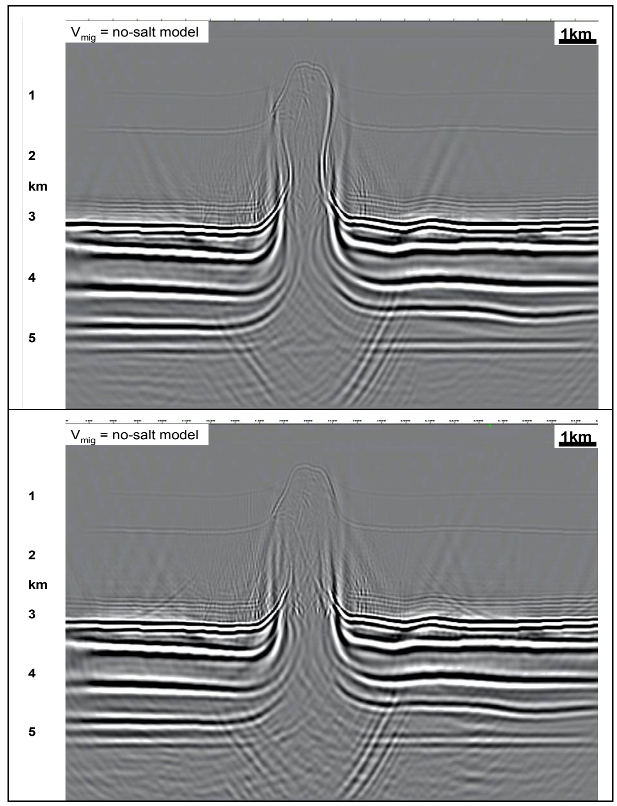
Effects on RTM migration

In figure 5 we see the RTM of the FD raw data using a no-salt sediment-flood model, and figure 6 shows the RTM image of the data subjected to Tau-P mute and ASMA. It is clear that the vertical and overturned salt-flank events have been seriously attenuated in the latter sequence.

Real Data

Having demonstrated the deleterious effects of inappropriate pre-processing on RTM imaging using the synthetic data, we also consider a real North Sea example. In fact it was the mixed success of RTM migration on such salt structures that alerted us to the issues described here. On one project (Farmer, et, al, 2006) the results were impressive, however, on a subsequent project involving a neighboring salt dome with similar geology and similar acquisition, the results of RTM were disappointing (in-part perhaps due to model inaccuracies, but possibly also due to the effects of slightly different pre-processing).

Figure 7 shows a CMP gather before and after a tau-p mute (designed to attenuate back scattered rig noise). An unusual event, similar to an apex-shifted diffracted multiple arrival is ‘successfully’ removed by the tau-p filter. However, from the modeling studies, it is believed that this event is a double bounce arrival. RTM migration of the real data before and after application of the tau-p filter supports this observation (figure 8).



Figures 5 & 6. RTM images of the raw data and the data processed with ASMA and Tau-P muting. The overturned salt wall reflectors have been significantly damaged by this conventional pre-processing flow.

Conclusions

Conventional pre-processing is designed to remove various classes of noise, such as backscattered energy, multiples, and diffracted multiples. The processes designed to do this, have for the most-part, been designed with one-way wave propagation of primary energy in-mind.

However, if we set-out to migrate two-way propagated primary energy, as is now possible with the new generation of migration algorithms (such as RTM), we need to ensure that our pre-processing flow is ‘fit-for-purpose’, and does not inadvertently damage the very events we are trying to image.

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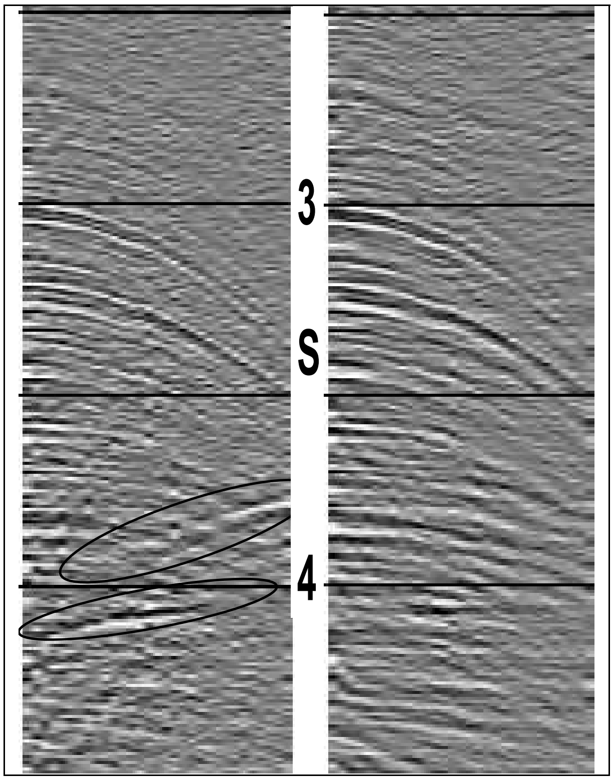

Figure 7. Left: a CMP gather after SRME (with maximum offset 3100m) for input to RTM. Note the events with their apex near 3800ms on the far trace, dipping in an opposite direction to the normal reflection events. Right: the gather after application of a Tau-P domain mute designed to attenuate back-scattered energy (thus affecting shifted apex CMP events). The contra-dipping events have been suppressed. Based on extensive modeling studies, these are suspected to be double bounce arrivals.

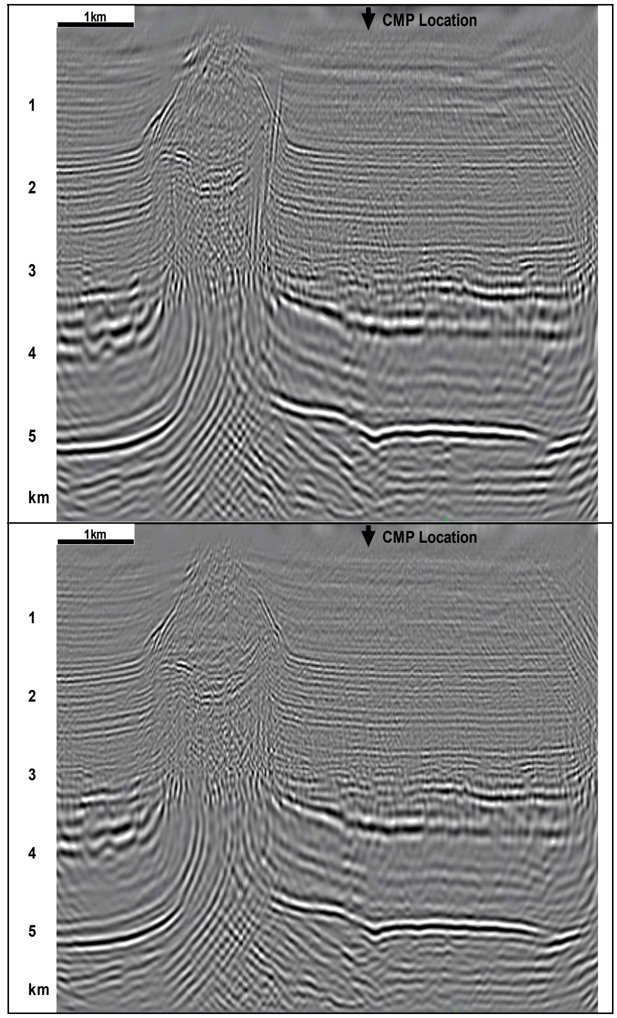

Figure 8. Top: 2D RTM of real data (after SRME multiple suppression) using a ‘no salt’ model. We see double bounce energy arrivals appearing as near-vertical events primarily in the vicinity of the right hand salt flank. Bottom: 2D RTM with the same model, but using as input the data after the Tau-P mute. The suspected double bounce energy has been removed. The surface location of the CMP shown in Figure 7 is indicated.

EDITED REFERENCES

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