Challenges and strategies of interbed multiple attenuation in the Asia-Pacific region

Min Wang[1*], Barry Hung[1], Xiang Li[1] and Stephane Fintz[1] demonstrate how to address the issues of interbed multiples in seismic data from the Asia-Pacific region.

High-quality imaging is key to reservoir characterization. Any events, such as interbed multiples, which are not specifically handled by migration algorithms, generate interfering events and distort the wavelets of true reflectors, thus reducing the quality of the final image. For instance, the presence of interbed multiples has a strong impact on the interpretation of fractured basements in Vietnam (Tan et al., 2010). These interbed multiples are generated between strong reflection horizons within the Oligocene and the top of the basement. In Cooper Basin, Australia, interbed multiples generated among the coal beds lower the high-frequency content and a time delay was observed in seismic characterization (Qi, 2013). This distorted imaging is a serious problem for seismic exploration and development. Interbed multiples are a common challenge in the Asia-Pacific region. Many multiple generators, such as the seafloor, carbonate layers, coal seams or volcanic flows, are found in this region, which generate visible interbed multiples. The impact of interbed multiples on inversion and interpretation has been quantified by analysing amplitude-versus-offset (AVO) responses (Iverson, 2014). The results showed that, when isolating subtle variations in rock properties, coherent noise can negatively impact the inversion results, creating a bias in the interpretation. It can be concluded that interbed multiples should either be removed before imaging, or must be correctly addressed in imaging algorithms.

Imaging using interbed multiples could be an advanced option in the future to increase imaging quality, as interbed multiples can provide complementary illumination coverage (Fleury, 2013). However, removal of interbed multiples before imaging is still the most practical, current solution. There are several methods available in the industry for attenuating interbed multiples. Parabolic Radon multiple removal is one such method, which relies on residual moveout of the multiple relative to a primary. This approach may work well for long-period multiples but often fails for short-period ones. Furthermore, it is difficult to attenuate multiples effectively well at near offsets. Interbed multiples consist of successive reflections between different interfaces and often have very similar kinematic behaviour compared to primaries. Therefore, different approaches are required for interbed multiple attenuation.

A model-based approach is a robust and popular way to address interbed multiples. When the generators of multiples are identified and separated by intermediate horizons, the convolution-correlation based method (Berkhout and Verschuur, 1997; Jakubowicz, 1998) can be a good candidate to solve this problem and is widely used in the industry (Griffiths et al., 2011). However, when several multiple generators are present in the subsurface, iterative modelling is required to attenuate all the multiples. Furthermore, horizon-picking is a challenging task for complex 3D surveys. In contrast, the inverse scattering series (ISS) method can predict all interbed multiples simultaneously without any prior knowledge of subsurface information (Weglein et al., 1997; Wang et al., 2014). It can therefore be a worthwhile approach when there is no knowledge of possible generators.

The ISS method predicts interbed multiples in the pseudo-depth domain. The input data – after surface-related multiple attenuation – are firstly pseudo-migrated into the depth domain using a reference velocity (usually water velocity for the marine case). These images can be considered as scattering points to predict interbed multiples. These predictions will necessarily include at least three reflections at scattering points, with a constraint that downward reflections should occur at shallower locations than upward reflections, which is called the 'low-high-low' ray path relationship (Nita and Weglein, 2007). The third-order scattering prediction is named the first predictor. In theory, there are infinite predictors that could be used to obtain a more accurate interbed multiple model. However, the first predictor can predict the first-order interbed multiples with correct traveltimes. In practice, we can successfully remove interbed multiples with the first multiple predictor by using adaptive subtraction to handle any amplitude difference between the actual interbed multiples and the predicted ones.

In the following sections, we first briefly discuss the challenges faced when using the ISS method for interbed multiple attenuation, followed by corresponding remedial

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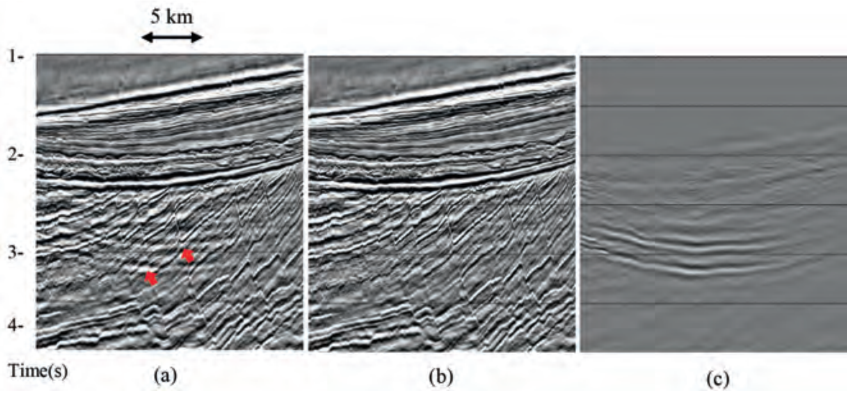

Figure 1 (a) Near-angle 3D PSTM stack section shows visible interbed multiples (indicated by red arrows) interfering with the fault structures, (b) near-angle 3D PSTM stack section after interbed multiple attenuation, and (c) corresponding interbed multiples removed from the data.

strategies. Then we demonstrate how we address the issues of interbed multiples in seismic data from the Asia-Pacific region. The first data example is from Western Australia, whereby multiples generated between the seafloor and shale layers have the same arrival time as the target zone. This poses significant problems for reservoir identification and characterization. The second data example, from Southern Australia, has more challenges for interbed multiple attenuation because it is a shallow water survey and there are many possible generators. The last example is from offshore Vietnam, where one strong layer (possibly carbonate), together with shallow layers, generates interbed multiples which are of relatively strong amplitude, masking a weak primary signal in the deep section. Consequently, the presence of interbed multiples causes difficulties for structural interpretation.

Challenges and strategies

The first challenge of interbed multiple attenuation is the identification of multiples, particularly when their residual moveout is small, thus making them kinematically similar to primary reflections. If suspected multiple events remain in the seismic data after surface-related multiple attenuation, then the interfering events could be interbed multiples. Without any requirement of prior knowledge of generators, the ISS method can predict all the interbed multiples. Fast 1D modelling on near-offset stack data may be sufficient to quickly check their arrival times. A comparison of the multiple model and seismic data helps us to judge whether suspected events are interbed multiples or residual surface-related multiples.

The second challenge is the resolution of the multiple model. As we know, the missing near offsets are normally extrapolated from recorded seismic data by partial normal moveout (NMO) correction for multiple modelling. For a shallow water survey, the missing near-offset data are difficult to extrapolate properly owing to the wavelet stretching (large traveltime difference versus offset at shallow section). Multiple models predicted with a stretched signal have distorted wavelets and low resolution, making subtraction difficult. In this case, we borrow ideas used for shallow water surface demultiple where the shallow primaries can be inverted from deepwater peg-leg multiples: the same concept can be used for shallow water ISS (SW-ISS) multiple attenuation (Hung et al., 2014). After utilizing inverted shallow primaries, interbed multiples generated from shallow reflectors can be well predicted with a broad frequency range. For the general case, broadband processing (Hung et al., 2015) provides seismic data with wider frequency content which therefore improves the resolution of the multiple model. It has been suggested that removal of source effects needs to be performed prior to ISS modelling (Weglein et al., 1997). In reality, wavelet effects cannot be removed completely, particularly in the deep section. Therefore, there is a limit to the capabilities of the ISS method when predicting multiples bouncing within layers thinner than the length of the seismic wavelet.

When the survey has significant crossline dips, 3D prediction is required to take into account the strong out-of-plane components. Extending the ISS method from 2D to 3D is straightforward in theory. However, actual implementation is more complex as 3D prediction requires an ideal data distribution (wide-azimuth). On conventional streamer data, we use the following approach to satisfy the regularized dense data requirement: (1) generate regularized wide-azimuth data by choosing appropriate traces from the input data (depending on some selection criteria that minimize the difference in azimuth, offset and midpoint) and then applying differential NMO to correct any discrepancy in offset; (2) perform 3D ISS for interbed multiple prediction on the regularized data; (3) map the interbed multiple model to the irregular locations according to actual shot-receiver coordinates. Once we have generated the multiple model, we perform adaptive subtraction to remove the interbed multiples from the input data. This technique allows true-azimuth 3D ISS interbed multiple attenuation. 3D ISS is generally more effective than the 2D approach because it takes into account the strong crossline dip of multiple generators (Wang et al., 2014).

Field data from offshore Western Australia

The first data example is from offshore Western Australia, where interbed multiples are a particular problem. Multiple attenuation is a key focus of the reprocessing effort in order to obtain optimal imaging in this area. Figure 1a shows a 3D PSTM near-angle stack section after surface-related multiple attenuation. With broadband processing, the imaging has high resolution. There are several strong events with gentle dips in the shallow section – these are Cretaceous layers. Beneath the sediments there is a large fault zone, which is the target area for this survey. The interbed multiples, indicated by red arrows in Figure 1a, are generated from shallow sediment events which interfere with the fault structures. The multiple generators have only a mild crossline dip. 2D ISS can therefore predict interbed multiples well. After adaptive subtraction, the interbed multiples are significantly removed from the data while primaries are preserved. Consequently, the fault imaging is much cleaner, as shown in Figure 1b. The removed interbed multiples are shown in Figure 1c where it can be seen that, besides the seafloor that gives rise to the downward reflection of the interbed multiples, there are other generators involved but they cannot be identified easily.

Shallow water data from Southern Australia

To illustrate the challenges of interbed multiple attenuation in shallow waters, we study a survey acquired in Southern Australia. Figure 2a depicts a near-offset stacked section after surface-related multiple attenuation. It shows that, besides the seafloor, a number of strong reflectors in the overburden are generators of interbed multiples. These multiples hinder the interpretation of primary structures in the target area (highlighted by the red box). Clearly, it would be difficult to use convolution correlation based multiple modelling for this case because there are many possible generators. In contrast, the ISS method can predict all the multiples in one pass without the need to explicitly identify any generators. The biggest challenge of interbed multiples in shallow water is the resolution of the multiple model. Conventional ISS predicts a multiple model with lower frequency, shown in Figure 2b (zoom-in section), because of a reliance on a stretched near-offset signal extrapolated by partial NMO. In comparison, the SW-ISS method provides a high-fidelity interbed multiple model, shown in Figure 2c. The shallow near-offset primaries used in the prediction are in reality inverted from deep peg-leg multiples. Figure 3 shows the near-offset section before and after interbed multiple attenuation. It can be observed that, although conventional ISS did a reasonable job in suppressing the internal multiples, it still left a considerable amount of remnant multiple energy – indicated by the arrows in Figure 3b, as compared to the result obtained by SW-ISS shown in Figure 3c.

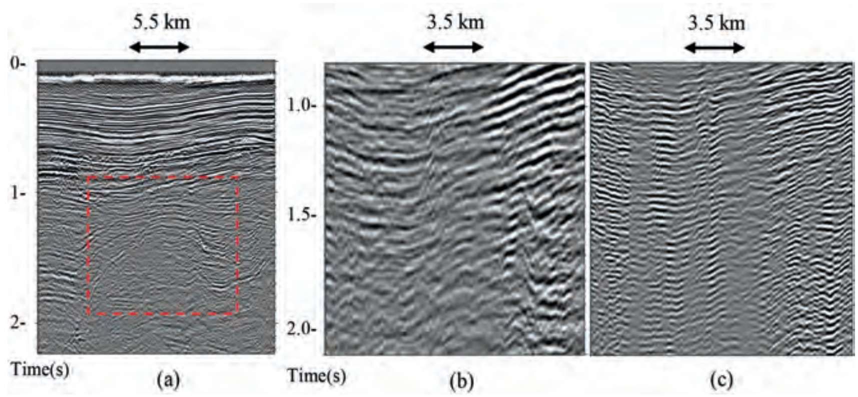

***Figure 2** (a) Near-offset stacked input after surface-related multiple attenuation shows shallow sediments with their interbed multiples highlighted by the red box, (b) conventional ISS multiple model of the highlighted section, and (c) the corresponding SW-ISS model.*

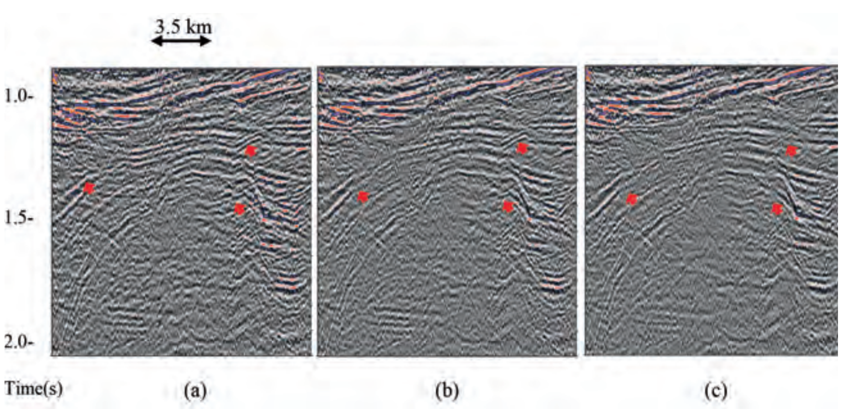

***Figure 3** (a) Magnified section of the input (red box in Figure 2a), (b) subtraction result obtained by conventional ISS, and (c) subtraction result obtained by SW-ISS.*

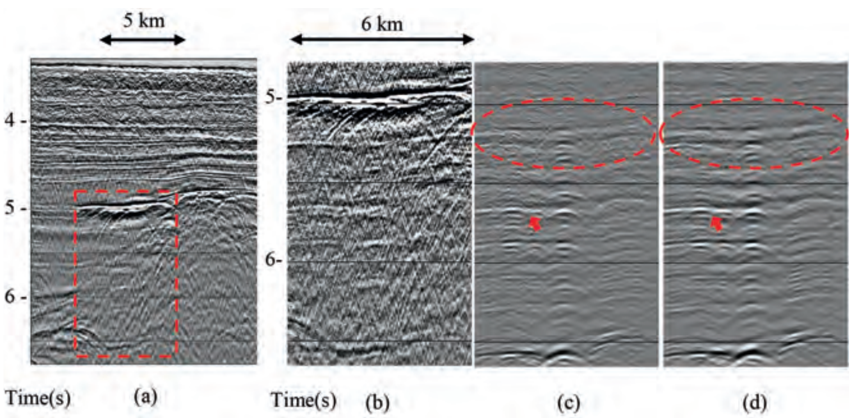

Figure 4 *(a) Near-offset stacked input showing strong reflectors between the water bottom and the strong layer (possible carbonate) around 5 s and their interbed multiples which mask weak primaries in the deep section. (b) Magnified input data in common offset 500 m, (c) corresponding 2D ISS multiple model and (d) 3D ISS model.*

Field data from offshore Vietnam

In this dataset from deepwater offshore Vietnam, there are quite a number of strong reflectors between the water bottom and a possible carbonate layer around 5 s two-way traveltime, as shown in Figure 4a. It can be observed that in the highlighted box, some events with gentle dips cross over other dipping weak events. It is clear that one set of events is not related to the true structure. The surface-related multiples have later arrival times, i.e. after 6.6 s, since the water bottom time is around 3.3 s. Therefore, those events are most likely to be interbed multiples. Figures 4b-d show the target zone in a near-offset section. With the ISS method all interbed multiples are predicted in one pass and their arrival times (Figures 4c and 4d) match the suspicious events that show up well in the data (Figure 4b). Therefore, we can be sure that those mildly dipping events are interbed multiples generated between shallow reflectors and the event assumed to be carbonate. The weak primaries in the deep sections are masked by interbed multiples, making structural interpretation difficult.

Although the shallow reflectors are quite flat, the complex structure of the carbonates introduces an out-of-plane component. Hence, for this dataset, the 3D prediction shown in Figure 4d provides a better, more continuous multiple model with a higher signal-to-noise ratio than the 2D model shown in Figure 4c. Figures 5b and 5c show the near-offset stack after multiple attenuation using the 2D and 3D ISS models, respectively. It can be observed that the 3D result is cleaner than the 2D result because of the more accurate multiple model.

Discussion

Interbed multiple attenuation is at an interesting phase of development for seismic data processing. There are still some challenges for which we do not have a reliable solution for the time being. The multiples generated within very thin layers (less than the length of a seismic wavelet) cannot be predicted correctly. Another issue is that an offset-dependent aperture cannot be defined for the ISS method since the prediction is performed in the wavenumber domain. Besides, the multiple prediction discussed in this paper, subtraction is another very important aspect. Interbed multiples are generally weak and always cross over with primaries, which makes L2-norm-based least-squares adaptive subtraction difficult because the matching filter is designed to minimize the difference between data and model. A compromise has to be found between the preservation of primaries and the attenuation of multiples. Curvelet-domain adaptive subtraction is therefore recommended since subtle dip separation of multiples and prima-

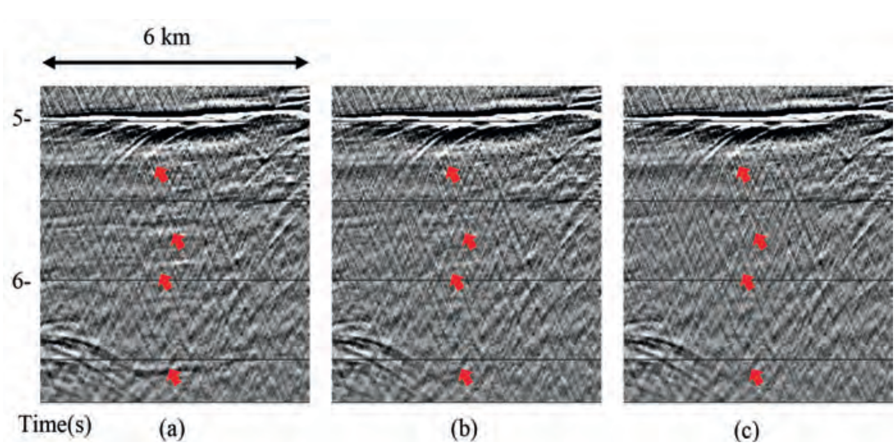

Figure 5 *(a) Magnified near-offset stack (red box in Figure 4a), (b) section after multiple attenuation with the 2D ISS model, and (c) corresponding 3D ISS result.*

ries can be used as an additional constraint (Wu and Hung, 2015).

Conclusions

To summarize, we have discussed some of the challenges of interbed multiple attenuation in the Asia-Pacific region. One of the major challenges is the difficulty in identifying the generators of the interbed multiples. Without any a priori knowledge of these multiple generators, the inverse scattering series method can be used to predict all interbed multiples simultaneously. Some strategies are promoted which improve the resolution of multiple models such as inverted near-offset data for shallow-water cases, and broadband processing can be applied before modelling. 3D prediction produces better multiple models for areas with strong crossline dips. Application on various field datasets from across the Asia-Pacific region shows that interbed multiples are a consistent problem but can be predicted well with the ISS method combined with associated strategies. After adaptive multiple subtraction, the multiples can be greatly attenuated within the seismic data to deliver a cleaner image and aid in structural and stratigraphic interpretation.

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