Case studies in 3D interbed multiple attenuation

David Brookes, ION Geophysical Corporation

Attenuating water-column multiples with 3D SRME has become common practice, but interbed multiples are not attenuated with this technique since these multiples do not reflect from the free surface. Interbed multiples are often reflected between closely spaced events, giving them an effective velocity very similar to primary events. Because there is little moveout discrimination, interbed multiples do not respond to Radon multiple attenuation or other moveout-based techniques. Extending the concept of SRME to predict interbed multiples is not a new idea, but the 3D implementation was not widely applied until recently. The increase in available computing power has made 3D IME (interbed multiple elimination) a viable option. This paper will discuss a synthetic data set, a Gulf of Mexico marine data set, and an Egyptian Western Desert land data set. Attenuating interbed multiples is an important issue in exploration, especially in the Middle East, where this type of multiple is particularly problematic because the anti-multiple tools based on velocity differences do not work well in this geologic setting. In the salt provinces, attenuating interbed multiples is of particular importance as their presence greatly inhibits interpretation. In addition, removing this class of multiple is very helpful in understanding dirty salt.

Interbed multiples

Problematic interbed multiples are frequently associated with an event with a strong reflectivity coefficient. Without this strong multiple generator, interbed multiples may be present, but are likely to have insignificant amplitude. Water-column multiples are reflected off the water surface, which has a reflection coefficient near –1, and the ocean bottom, which is typically one of the strongest events in the section. Conversely, interbed multiples have three reflections in lower-contrast media. The energy of the interbed event is therefore attenuated as it is related to the product of the three reflection coefficients. A multiple reflection of a mere 1% of incoming energy requires an average reflection coefficient of the three reflections of no less than 0.2. Because of this, most significant interbed multiples have their two bottom bounces on a common anomalously bright event. That event ends up acting as a mirror for the events above. Common examples are top of salt, carbonates, and volcanic or coal layers. The generator is an important input to the IME removal process, as it is needed to help build the prediction. Identifying such an event therefore is required for affordable implementation of IME.

Interbed multiple elimination

IME is an extension of the SRME algorithm. In SRME, a multiple prediction is created by convolving traces sharing endpoints on the surface. We can think of a seismic trace from surface point A to surface point B (T_{AB}) as a sum of primary events (P_{AB}), surface-related multiples (SM_{AB}) (when working with marine data), and interbed multiples (IM_{AB}):

$$T_{AB} = P_{AB} + SM_{AB} + IM_{AB} \tag{1}$$

In 3D SRME algorithms, the surface multiples are approximated by a sum over possible surface reflection locations (B) of possible multiples created by convolving the traces sharing the endpoints:

$$SM_{AB} \cong \sum_{C} T_{AC} T_{CB} \tag{2}$$

Figure 1a illustrates an SRME multiple candidate raypath. Multiple models obtained in this way are approximations of the true multiple path in several ways: the spectrum is squared, the aperture is limited, and since multiple-iteration SRME is not typically used, the relative amplitudes of double bounce multiples, triple bounce multiples, etc. are incorrect. These approximations are typically accurate enough that adaptive subtraction is sufficient to remove them. Adaptive subtraction is used to subtract the multiple predictions from the original data to get a "primary" data set:

$$P'_{AB} = T_{AB} - SM_{AB} \tag{3}$$

Of course, this primary data set still contains interbed multiples which, following SRME, can be removed by IME. IME extends SRME by integrating over two surface locations (C and D) instead of just one. Two traces (from the SRME results) which do not share a surface location are convolved, giving a trace with raypaths like the one illustrated in Figure 1b. This convolution produces a trace which has no physical meaning with respect to seismic acquisition. The nonphysical trace is then correlated with the third trace which has source and receiver at points C and D.

$$IM_{AB} \cong \sum_{C} \sum_{D} P'_{AC} P'_{DB} P'^{*}_{CD} \tag{4}$$

The correlation removes the nonphysical raypaths, creating an interbed multiple model trace with a reflection point on a subsurface event (Figures 1c and 1d). Again, IME generates approximations to the actual interbed multiple requiring the use of adaptive subtraction to give a primary data set with attenuated interbed multiples:

$$P_{AB} = P'_{AB} - IM_{AB} \tag{5}$$

There is a complication in the technique, however, because the IME prediction can contain primary events if not properly implemented. Because most interbed multiples have relatively short periods, the surface points (C and D) are often close to the shot or receiver of the original trace. As these surface points get close, the P'_{CD} trace may become sufficiently similar to one of the other traces to simply cancel it:

$$\text{If, } P'_{DB} \approx P'_{CD} \text{ then } P'_{DB}P'^{*}_{CD} \cong 1 \quad \text{(at least kinematically)}$$

$$P'_{AC}P'_{DB}P'_{CD} \cong P'_{AC} \qquad (6)$$

To prevent this, a generator horizon must be provided. By limiting traces P'_{AC} and P'_{DB} to events below the generator, and limiting trace P'_{CD} to events above the generator, only events with multiple raypaths intersecting the generator horizon will be present in the prediction. An example mute horizon is shown in Figure 1c. This method has been used in the industry for some time in 1D and 2D versions, and has been described in the literature by Verschuur (2000), Weglein (1997), and Van Borselen (2002) among others. The computational effort need to run 3D IME is quite significant. Thus, even though well known, the algorithm has not enjoyed widespread deployment. Where the computational effort for 3D SRME is proportional to the area in the aperture, the computational effort for 3D IME is proportional to the square of the aperture area. In spite of this, with careful preparation and parameterization, the com-

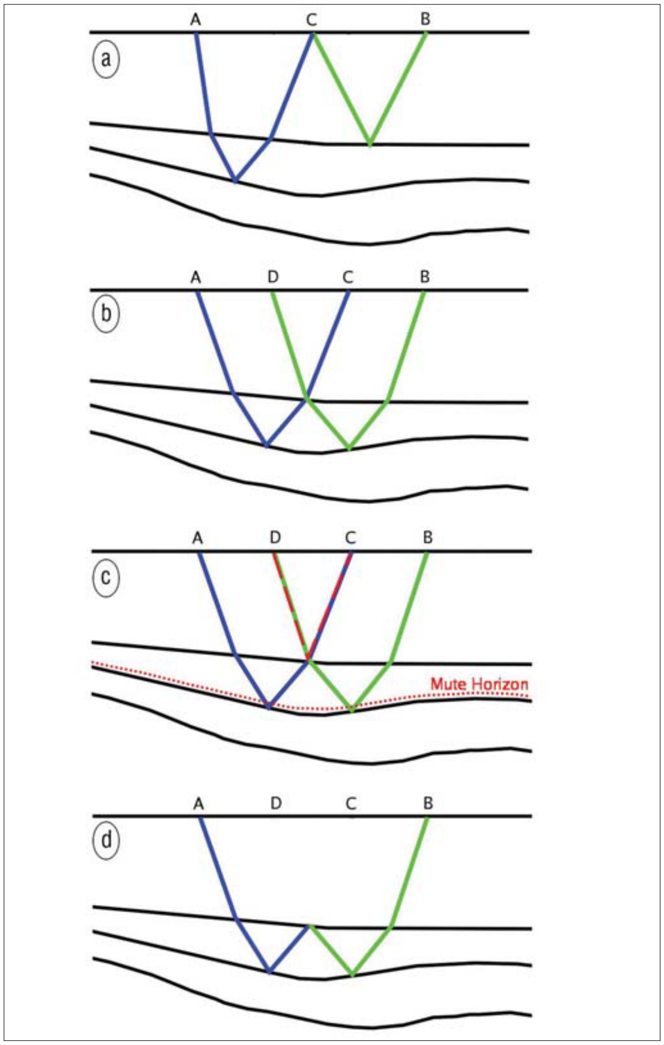

Figure 1. *(a) SRME multiple prediction. (b) Traces AB and CD are convolved. (c) Trace CB is correlated, removing the extra path. (d) The result is a potential interbed prediction for trace AD.*

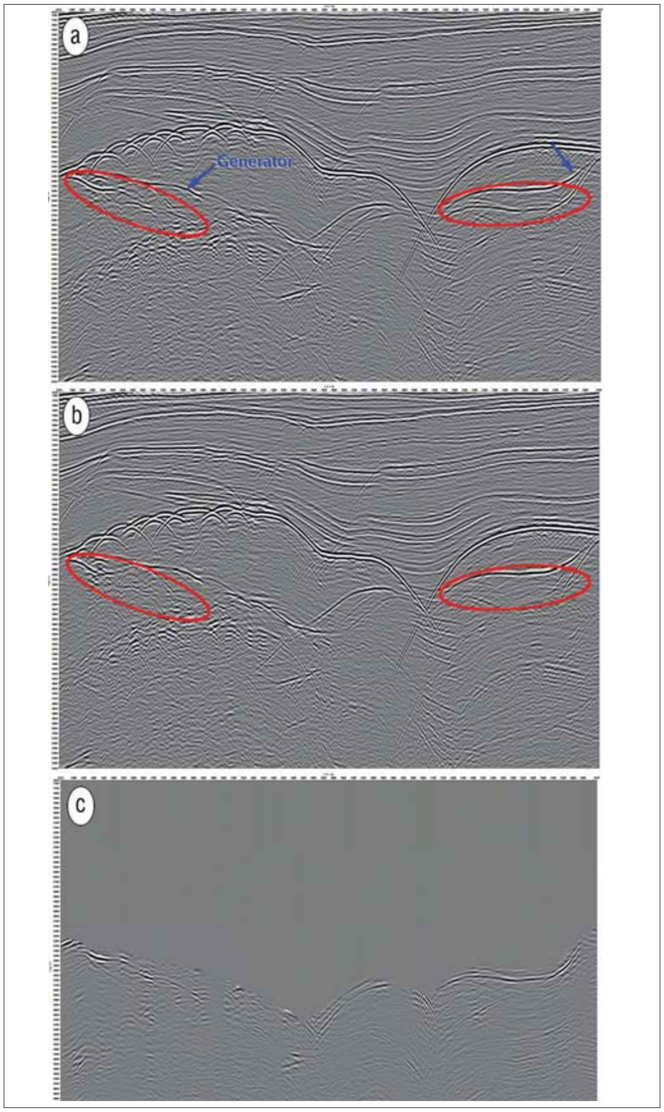

Figure 2. *(a) Pluto model, the input to IME. (b) Pluto model with interbed multiples attenuated. (c) Removed interbed multiple.*

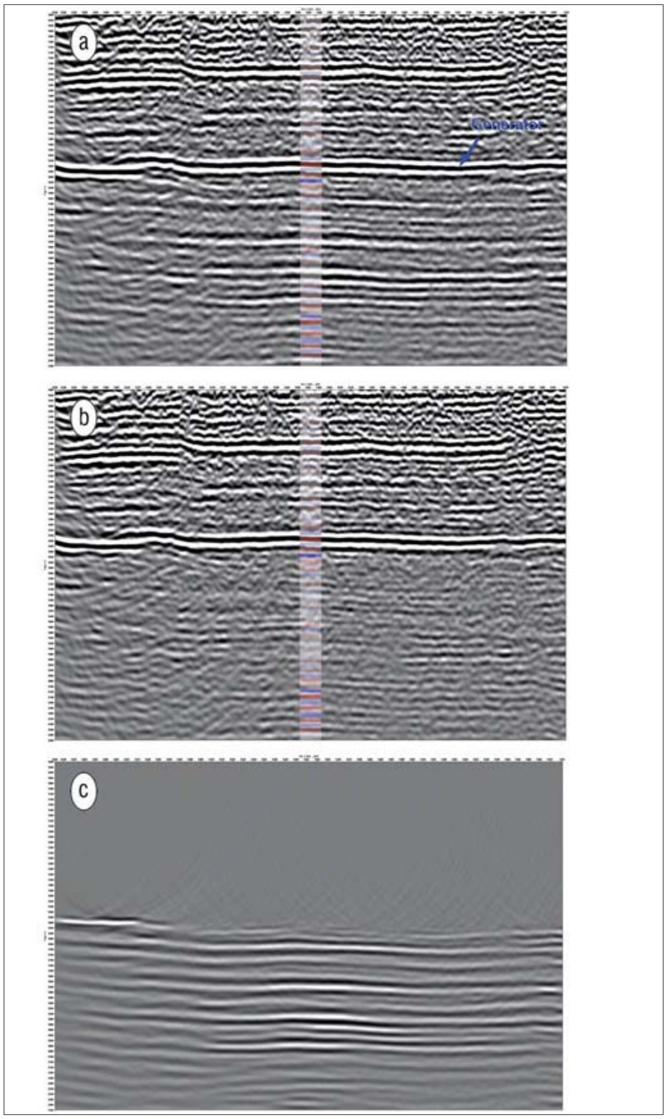

Figure 3. *(a) Egyptian Western Desert data with well synthetic overlay, (b) with interbed multiples attenuated, and (c) removed interbed multiples.*

putational cost for 3D IME can be as little as twice that of 3D SRME. This reduction in computational effort has been achieved while providing the same level of attenuation of interbed multiples as is now common with surface multiples using 3D SRME.

Pluto test

The Pluto synthetic model has long been used as a validation test for multiple attenuation. It is a reasonable simulation of geology in the Gulf of Mexico. The model contains quite a bit of multiple energy, including some significant interbed multiples. The main generator for interbed multiples is the base of salt. The main multiple mechanism is an intrasalt multiple reflecting off the base of salt, reflecting off the top of salt, and then a second reflection on the base. The high reflectivity of salt boundaries and the relatively smooth base and top in the Pluto model generate high-amplitude multiples. While intrasalt multiples are not particularly common in field data, this multiple mechanism is not uncommon in that the generator (base of salt) is acting as a mirror for events above it (top of salt). Figure 2a illustrates the input data. Figure 2b shows the data with interbed multiples attenuated, and Figure 2c shows the multiple energy removed. Several complex intrasalt multiples are well modeled and removed.

Western Desert

The Western Desert in Egypt has an interbed problem similar to many onshore areas. The shallow sediments, typically consisting of sand and shale layers, are easy to image. Around 1600 ms into the data is a high-reflectivity layer of carbonates. The high reflectivity of this layer reflects much of the seismic energy, leaving the events below to be illuminated by only a fraction of the source wavefield. The high-reflectivity event also acts as a mirror for the events above. The resulting section is doubly difficult to interpret because the primary reflections are weak, the interbed multiples are strong, and there is not much dip difference between the two. The similarity of the dip of primary and multiple events can raise the question of

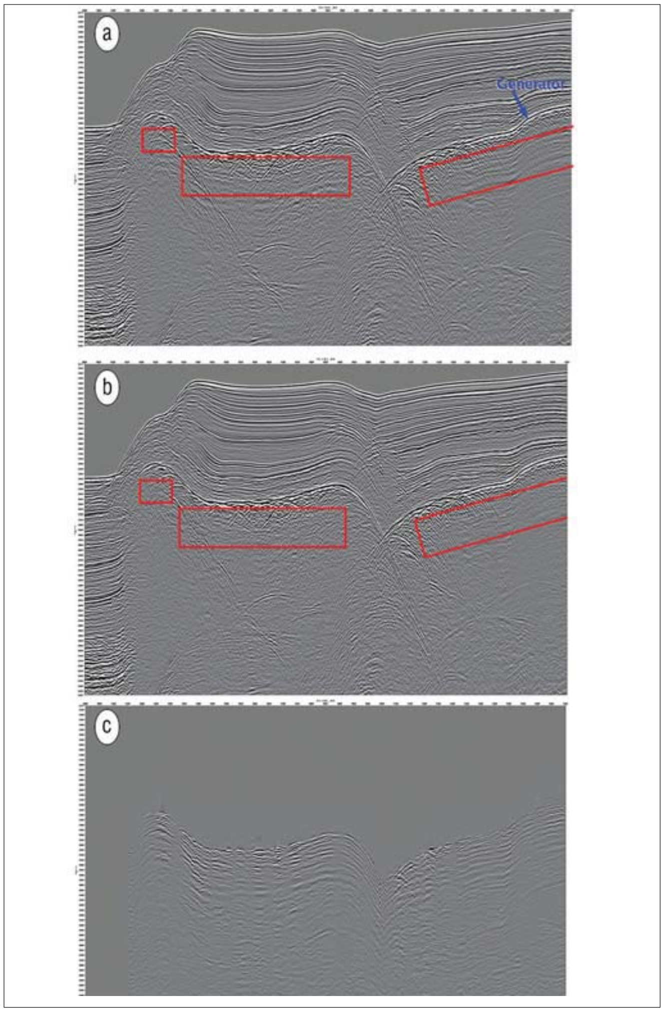

Figure 4. *(a) Gulf of Mexico data showing interbed multiples off the top of salt, (b) with interbed multiples attenuated, and (c) removed interbed energy.*

whether the correct events are removed. Figure 3a shows an example of Egyptian desert data. Figure 3b shows the data with multiples attenuated, and Figure 3c shows the removed multiple energy. With little dip discrimination between primaries and multiples, well-log synthetic data are useful in verifying that the multiples are being removed while the primaries are being preserved. The blue and red overlay on Figures 3a and 3b shows a primary-only synthetic trace derived from a well log. The events removed by IME do not match events on this synthetic, while those that remain show good agreement with the well.

Gulf of Mexico

The Gulf of Mexico has large areas of tabular salt. The high reflectivity of the salt boundaries is conducive to interbed multiple generation. Figure 4a shows an example of tabular salt and its interbed multiples. The generator in this case is the top of salt which acts as a mirror to the sediments above the salt. These interbed multiples interfere with the interpretation of the base of salt as well as mimicking subsalt reflectors. Removing salt-generated multiples also clarifies the presence or absence of entrenched sediment in the salt bodies and the presence of "dirty salt." Figure 4b shows the data with attenuated internal multiples, and Figure 4c shows the multiple energy removed.

Conclusion

3D interbed multiple removal is being successfully applied to diverse sets of data in both land and marine environments. The resulting multiple attenuation is in line with what has become standard with 3D SRME and is achieved with only a slight increase in time and computational effort. TLE

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Corresponding author: David.Brookes@iongeo.com