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Imaging Oblique Reflectors with Prestack Migration

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Summary

One of the assumptions for 2D seismic data processing is that the line is oriented at right-angles to the geological structure, i.e. in the dip direction. Reflectors that are oblique to this 2D seismic line require special processing for optimum imaging. This can be achieved by modifying the poststack or prestack migration velocities. However, we illustrate that the sensitivity of prestack migration to perturbed velocities can make it a poor choice for imaging the oblique reflectors. A better method is to use the prestack migration at 100% velocities, then apply a residual migration to simulate a modified poststack migration.

Introduction

The problem of oblique reflectors is resolved by using 3D seismic data. However, there are many 2D lines that do have economic value in areas where there is no 3D data, or there may be new 2D data that is acquired with very high resolution. These 2D lines retain the problem of oblique reflectors and can benefit from special processing to enhance oblique reflectors.

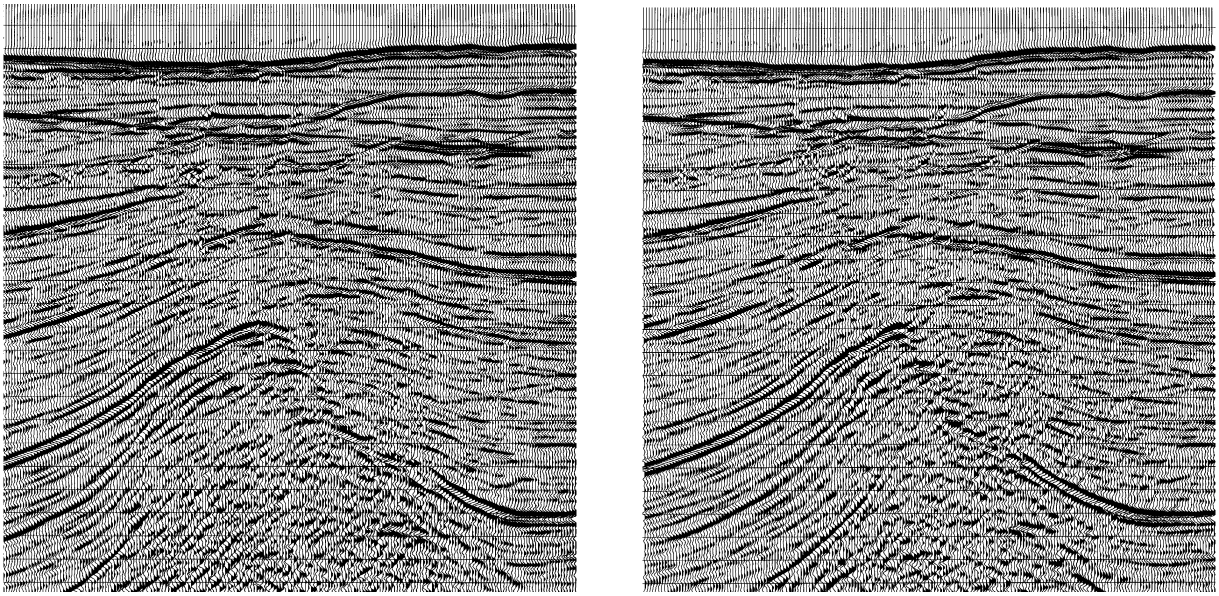
French (1975) indicated that reflectors that are oblique to a 2D line can be focused during the migration process by raising the migration velocity V_{mig}, by dividing the RMS velocity V_{RMS}, by the cosine of the obliquity angle γ, i.e.,

$$V_{mig} = \frac{V_{RMS}}{\cos\gamma}, \tag{1}$$

where the angle γ is measured from a normal to the line. The migration is assumed to be 2D poststack and will focus only the oblique part of the data and over-migrate the data that is not oblique. Typical tests would migrate the data at various percentages of V_{RMS}, allowing us to choose the best focusing of a suspected oblique reflection. The migration velocity could then be used to estimate the angle of the oblique reflector. An example in Figure 1 shows two 2D poststack migrations of the same zero-offset data with migration velocities (a) at V_{RMS} and (b) at $1.3 \times V_{RMS}$. Note the appearance of a dipping fault in (b) that is not apparent in (a), but also note the over migration of other areas of the section in (b).

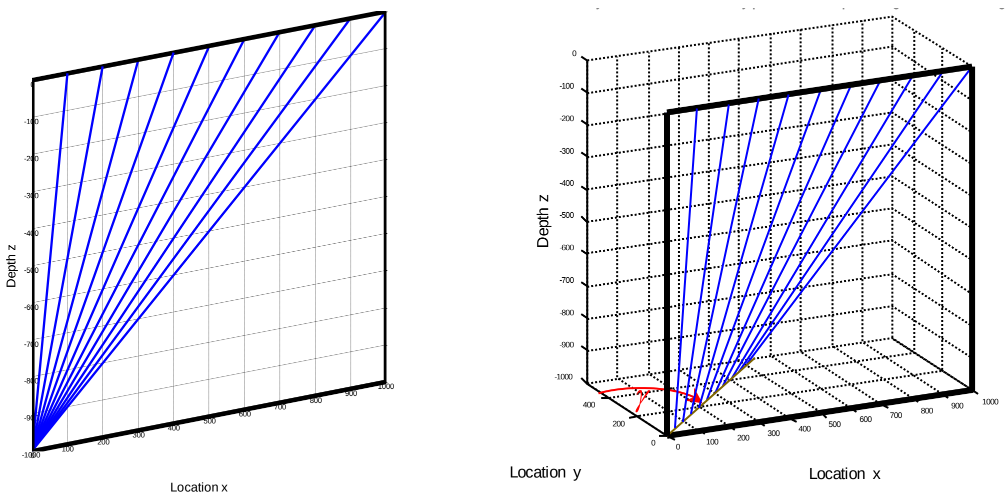
Theory

Figure 2 shows ten zero-offset locations at 100 m increments on the surface, with blue lines representing the raypaths to a reflector at a depth of 1000 m. In (a) the reflector is normal to the 2D line and all raypaths are in a vertical plane below the seismic line. In (b), the reflector is at an oblique angle of 45^o and the zero offset reflection points move away from the vertical plane as the displacement is increased. The traveltimes in both figures form a one-sided "diffraction", and are both hyperbolic in a constant velocity medium. Geometry will verify that the oblique raypaths are shorter, and will have a hyperbolic shape that is "broader" than the normal reflector. This broader hyperbola will have a higher migration velocity as given in equation (1).



a) b)

Figure 1: 2D poststack migration at a) V_{RMS} , and b) at $1.3\times V_{RMS}$.



a) b)

Figure 2: Zero-offset reflections from a) a normal reflector, and b) an oblique reflector at 45°.

Prestack imaging of oblique reflectors was discussed in Bancroft and Ursenbach (2000) where the traveltimes for an oblique reflector in prestack migration may be computed from

$$T_a^2 = T_0^2 + \frac{4x^2\cos^2\gamma}{V_{RMS}^2} + \frac{4h^2}{V_{RMS}^2}, \tag{2}$$

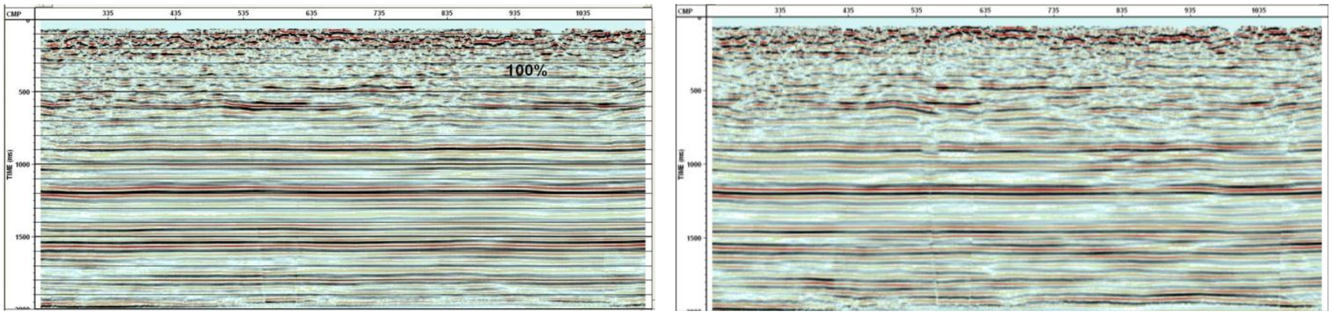
and

$$T_b^2 = T_0^2 + \frac{4x^2\cos^2\gamma}{V_{RMS}^2} + \frac{4h^2\cos^2\gamma}{V_{RMS}^2} = T_0^2 + \frac{4\cos^2\gamma}{V_{RMS}^2}\left(x^2 + h^2\right), \tag{3}$$

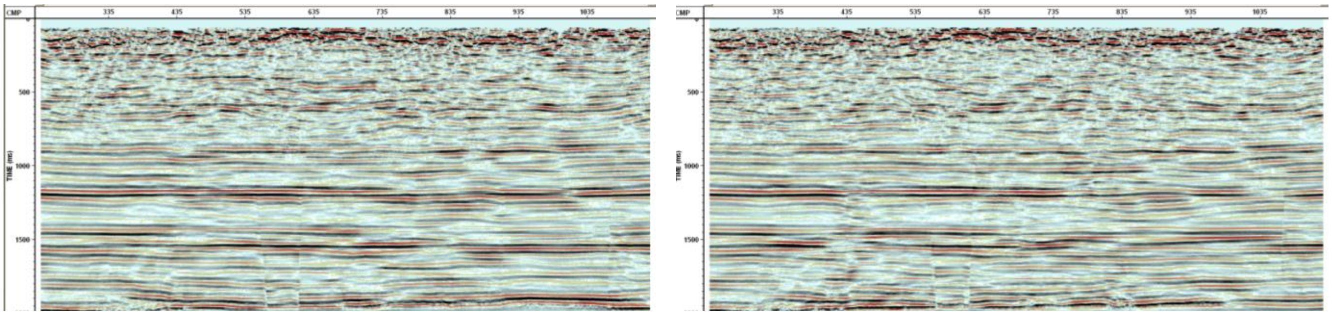
where h is half the source-receiver offset, and x the distance from the common midpoint (CMP) to the location of the migrated trace. Both equations were implemented in MATLAB code to evaluate their effect, and the results of equation (2) are shown in Figure 2.

Examples

A series of oblique Kirchhoff prestack migrations were created on the “low dwell” 2D line from the Hussar data set that is 4.5 km long. This data was acquired in 2011 from an area located in a sedimentary basin area near Hussar, Alberta, Canada. The prestack migrations were created using RMS velocity $V_{RMS}(x, t)$ that were incremented from 100% to 150%: Some of these results are shown in Figure 3. The results at first appeared to be amazing as many fault like features appeared to focus at various percentages.



a) 100% V_{RMS} b) 120% V_{RMS}



c) 140% V_{RMS} d) 160% V_{RMS}

Figure 3: Various section with different prestack migration velocities, a 100%, b) 120%, c) 140% and d) 160%.

We believe that the “features” are anomalous and not real, and are caused by slight changes in the spatial velocities $V_{RMS}(x, t)$. The velocities were estimated at 500 m intervals and were not smoothed.

An initial suspicion was the sharp discontinuity visible at the bottom of all the sections of Figure 3. The maximum time of these migrations corresponded to the maximum time of the input data, where the migration aperture would not permit such a high spatial resolution. Another observation was that some of the apparent “events” moved spatially, rather than focus at the same spatial location, typical of oblique reflectors when using poststack migrations.

One possible explanation is that kinematic shape of the 3D prestack migration operator (Cheops pyramid in a constant velocity medium) is able to form more areas of tangency with anomalous data than the poststack process that has a 2D migration operator approximated with an hyperbola.

When the velocity model was held spatially invariant $V_{RMS}(t)$, the artifacts were significantly reduced or completely disappeared, as illustrated in Figure 4.

The sections in Figure 4 were created from a prestack migration with 100% velocities, and then applying residual migrations (Larner and Beasley 1987, Rothman et.al. 1985, Stolt 1996, and Fomel 2003) at various residual velocities V_{res}.

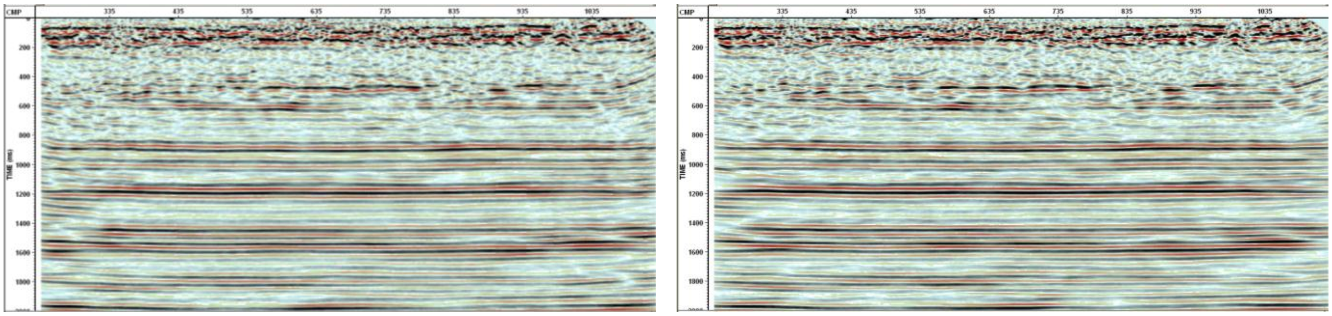
Residual migrations allow us to simulate a poststack migration at different velocities $V_{mig} = kV_{RMS}$ by applying a residual migration with velocity V_{res} where

$$V_{mig}^2 = V_{RMS}^2 + V_{res}^2 = k^2 V_{RMS}^2 , \tag{4}$$

or

$$V_{res}^2 = V_{RMS}^2 \left(k^2 - 1\right), \tag{5}$$

where k is the fraction of V_{RMS}. If we desire a poststack migration of 120% V_{RMS}, (1.2 V_{RMS}) then the residual velocity will be V_{res} = 0.66 V_{RMS}, giving the result illustrated in Figure 4a.



a) V_{mig} = 0.66V_{RMS} to simulate 120 % b) V_{mig} = 1.12V_{RMS} to simulate 150 %

Figure 4: Poststack residual migrations to simulate a poststack migration of a) a 120% and b 150%.

Conclusions

Oblique reflectors on a 2D line can be imaged by modifying the migration velocities. We show examples where modifying a prestack migration to accommodate oblique reflectors produced artifacts that were not real and brought into question the value of the method. There are a number of other tests that could involve prestack residual migrations (Al-Yahya and Fowler 1986), but were not required as we achieved those results by simply repeating the complete prestack migration with various velocities.

Poststack migrations with spatially constant velocities virtually eliminated the artifacts. These poststack migrations were created from one prestack migration that was re-migrated using the residual migration process.

Acknowledgements

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