Migration of Duplex Waves

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Summary:

When a seismic dataset is acquired all types of wave modes are recorded. These include primary reflected energy, as well as direct, multiple, shear and mode converted waves to name a few. Most data processing is targeted towards enhancement and positioning of primary reflected energy while the other wave modes are deemed noise and suppressed. One type of wave mode, duplex waves, are routinely found in seismic datasets that have near vertical subsurface features. The term duplex wave describes propagation paths with a double reflection involving a reflecting base boundary and a near vertical feature. The purpose of our study was to examine the possibility of using duplex waves to directly image vertical features. Here, we demonstrate concepts through the use of synthetic and a 3D field data example.

Introduction:

Conventional time domain data processing discriminates against duplex waves through the explicit use of hyperbolic moveout assumptions. Modeling results show that duplex waves have kinematics that severely differs from primary reflected waves, thus procedures such as NMO, DMO, and pre-stack time migration stack out duplex waves. Pre-stack depth migrations are still designed to correctly image primary reflected energy too. Also, most commonly used migration algorithms are challenged to image vertical features such as faults and flanks of salt bodies in the event that primary reflections were actually recorded. Other researchers have considered using doubly reflected energy.

In the work of Lutsenko (1987) was shown that duplex waves reflected from sides of salt domes are very strong. In the patent of Bell (1991) the method of imaging the vertical boundaries using duplex waves in the media without lateral velocity changes was proposed. The work of Broto and Lailly (2001) discussed the typology of prismatic reflections (which are the duplex waves too) and attempted to invert prismatic travel times on a synthetic 3D salt bubble dataset. Their work experienced difficulties when the straight forward use of reflection tomography became unstable. Due to the sparse number of rays, some source-receiver travel time pairs to not exist leading to non convergence in the inversion procedure. Cavalca and Lailly (2004) attempted to overcome this difficulty by restricting the inversion procedure to a set of admissible models where prismatic reflections exist for all source-receiver pairs. This approach reduces the general applicability of the method. We have chosen to perform pre-stack depth migration by expressly designing a migration operator for duplex waves.

Method

Migration of duplex waves is based on the Kirchhoff transformation (though it can be realized using some other kinds of transformation, e.g. finite difference) in which the Green's function is changed according to the kinematics for duplex waves. For real field datasets the interval velocity model obtained from pre-stack depth migration is used to migrate duplex waves. In order to enhance the stability of the process as well as speed it up, a base subhorizontal reflection boundary should be specified. The base boundary is chosen based on its pervasive continuity throughout the survey and proximity to the subvertical feature to be imaged. More than one base boundary can be used and it is picked after the dataset has been conventionally migrated.

In duplex wave migration, the main energy contribution is made be waves with large angles of incidence. This creates the opportunity to adapt duplex wave migration algorithms to migrate converted P-S waves and other waves with subcritical angles of incidence.

Synthetic Dataset

A synthetic 2D model was created mimicking a salt structure. Figure 1a shows the layering and velocity information as well as the key ray paths. Two types of duplex waves are shown Type 'i' reflects off the base boundary then off the flank of the salt structure before returning to the surface. Type 'p' first reflects off the salt flank then the base boundary before returning to the surface. Figure 1b shows the time lapsed wavefield at 100 ms increments computed via a full waveform modeling package. Superimposed is the outline of the salt structure and base reflector boundary in time. Through careful inspection of all the wave modes we were able to identify and highlight the duplex wave. Figure 2a depicts the shot gathers for model locations 1600 m and 1700 m with duplex waves again highlighted. The duplex waves have a presentation similar to multiple reflections with a large moveout contrast with respect to primary reflections. We expect that due to the large difference in moveout that duplex waves will simply be eliminated in the stacking process.

Figure 2b is a conventional Kirchhoff migration of the resultant stack. Notice that there is no suggestion of the duplex wave or the vertical salt flank. Furthermore, Kirchhoff migration, which relies on the constructive/destructive summation of energy, has feathered the imaging of flat events into the salt region making the determination of salt flank location uncertain. Figure 2c is the result of pre-stack duplex wave migration. Travel times were computed via ray tracing through the known model for duplex waves and used in Kirchhoff depth migration. A vertical event in the correct position of the salt flank was imaged.

Field Data Example

A salt structure form the Dnieper-Donetsk region of the Ukraine was used to field test duplex wave migration on a 3D dataset. No special steps were taken during acquisition to collect the duplex wave information. The structure can be characterized as a salt stalk with a welded overhanging salt cap. Traditional time domain processing experienced classical imaging difficulties: poor imaging of subsalt events, feathering of events into the salt leading to ambiguity in the placement of the salt flank. The dataset was processed through 3D pre-stack depth imaging to address subsalt imaging issues. While the imaging of subhorizontal events improved, there still was no direct indication of position of the salt flanks. During time and depth domain processing, no special procedures were used to enhance the duplex waves. Using the interval velocity model developed from pre-stack depth migration and interpretation of one strong subsalt reflector to serve as the base reflector, duplex wave migration was conducted over a portion of the 3D survey. The purpose of the duplex wave migration is to determine the location of the salt flank not to improve the imaging of horizontal events.

The 3D duplex wave migrated cube dataset was comprehensively interpreted in several orientations as in conventional interpretation. Specifically, X, Y, and diagonal vertical sections as well as horizontal sections through the duplex wave migration cube were analyzed. Figure 3 is a composite diagram depicting the results of the interpretation. The blue outlines on the contour maps indicate the region of the larger 3D where 3D pre-stack duplex wave migration was performed. The contours maps show the original interpretation (Figure 3a) and the interpretation based on duplex wave migration (Figure 3b) for events that lap onto the salt stalk. Figure 3c shows horizontal slices through the duplex wave migrated cube. The additional information from duplex wave migration revealed a much more complex salt structure. Portions of the salt have been removed exposing potential drilling locations. Also, numerous faults have been identified indicating a more complex reservoir compartmentalization scheme. On the original interpretation the well location marked in red is approximately 50 m from the edge of the salt flank. Under normal drilling operations this well would not be drilled because it was deemed too close to the salt flank. With the revised interpretation this was now a viable drilling location and indeed a well #4 was drilled. A cross section between points C-C was constructed and displayed on Figure 3d. It shows the revised interpretation of horizons and well trajectory.

Conclusions

Duplex waves are routinely recorded on seismic surveys in the vicinity of vertical features. As conventional processing is targeted to processing primary reflections, duplex waves have been suppressed. A 2D full waveform modeling experiment has shown that duplex waves are readily identifiable and exist in reflection strength and abundance and they can be used to image vertical features such as faults and salt flanks. Further, we conclude that a carefully performed pre-stack depth migration yields an interval velocity model that is sufficiently accurate enough to be used for pre-stack depth migration of duplex waves.

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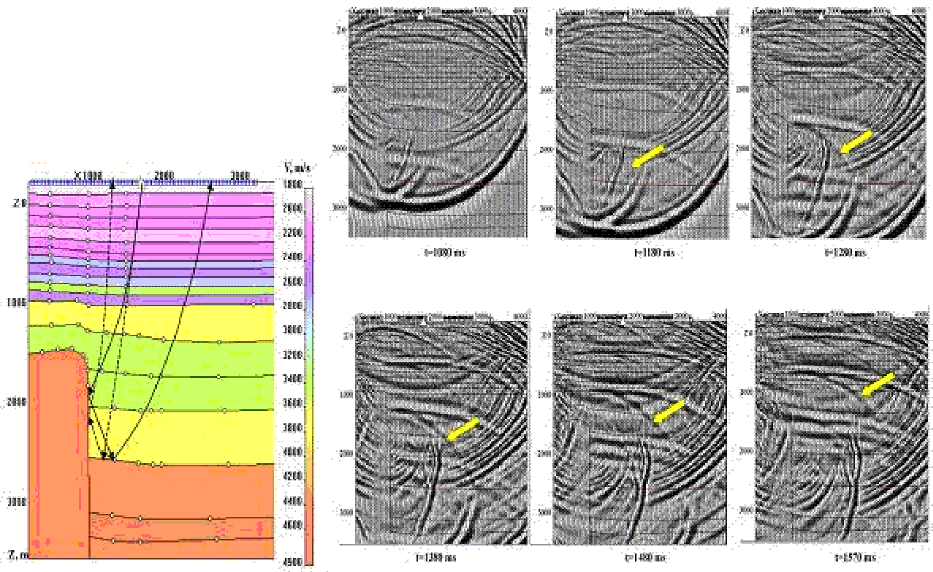
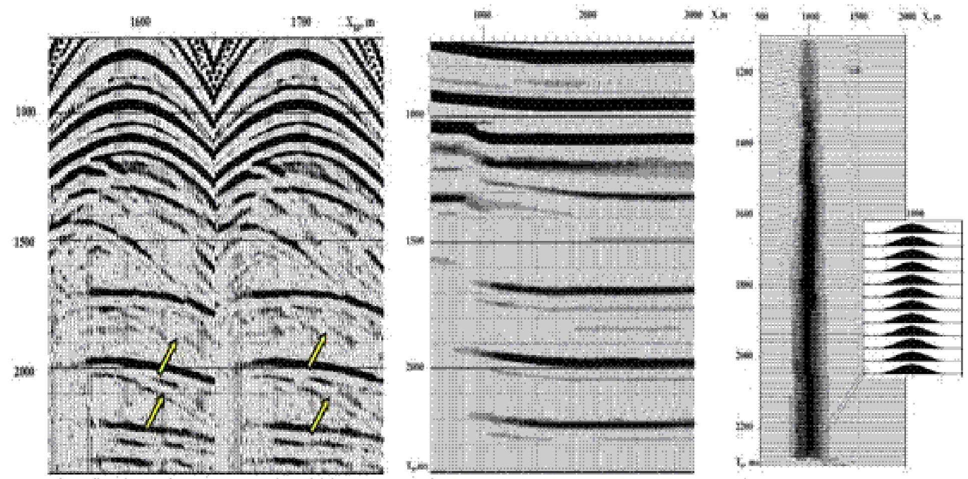


(a) (b)

Figure 1: (a) Model of salt dome; (b) Seismic wavefield snapshots (duplex waves highlighted)



(a) (b) (c)

Figure 2: (a) Synthetic shot gathers (duplex waves highlighted); (b) Conventional migration; (c) Duplex wave migration

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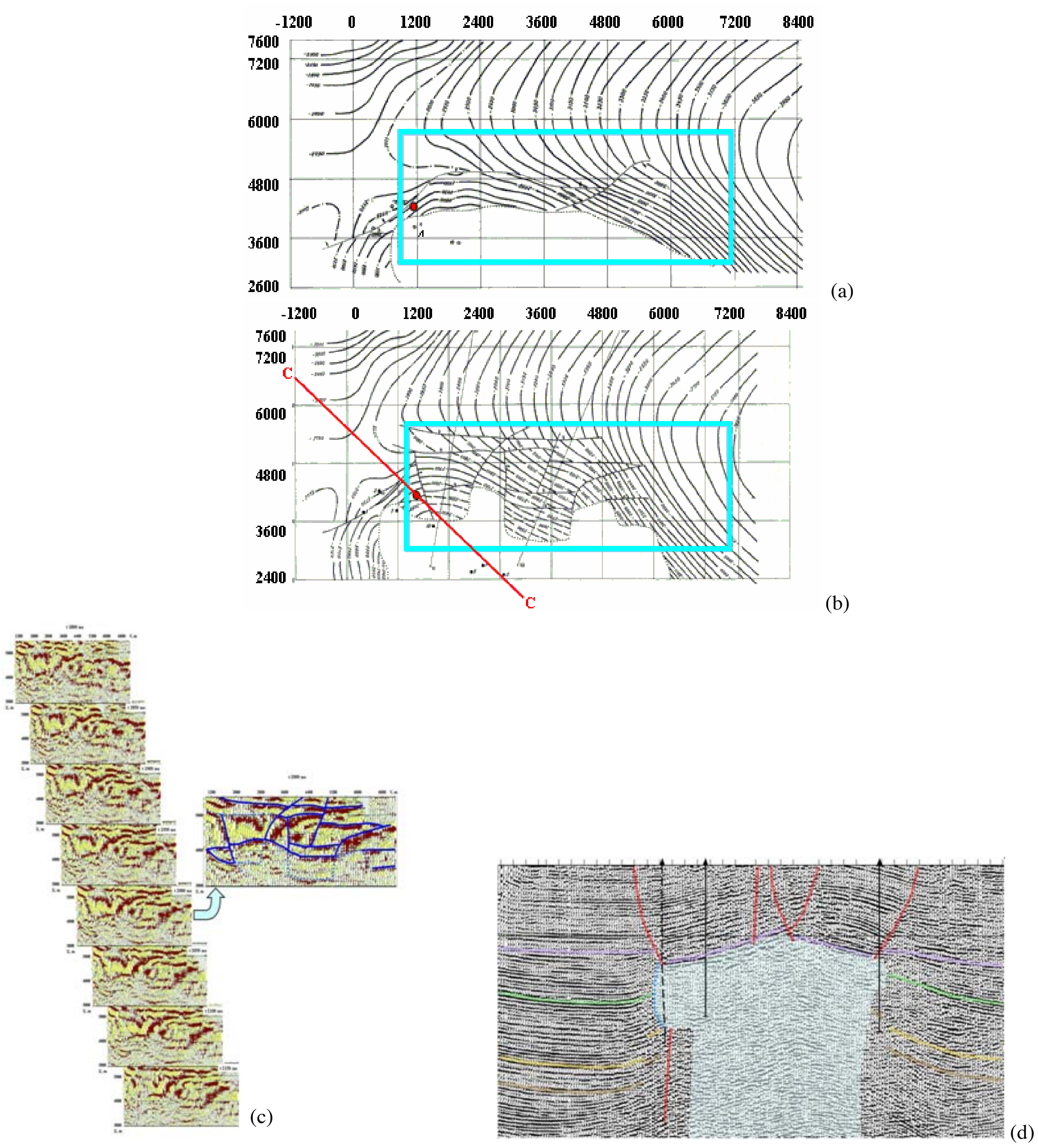

Figure 3: (a) Original interpretation (b) Interpretation with duplex wave migration (c) Horizontal slices of duplex wave migrated cube (d) Seismic cross section C-C

EDITED REFERENCES

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