GeoConvention 2015
GEOSCIENCE new horizons
Telus Convention Centre • 4-8 May 2015 • Calgary, AB Canada

Investigating fault shadows in a normally faulted geology

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Summary

Fault shadow poses a potential development risk and prevents exploration of deep resource plays. Here, we present a study that uses 2D finite difference modeling and a one-way wave equation depth migration method to investigate weak illuminations in footwall reflectors. We examined the quality of footwall imaging from poststack and prestack migrations with true model and with velocity estimates from iterative migrations. Appearances of fault shadow effect were seen on the geologic section as time anomalies, in poststack time migrations as distorted reflections which appeared as another sub-seismic fault. In the depth migrated images, they occurred as anticlines and synclines that contradicts the geology. We observed a confined section of the footwall was poorly illuminated. Results from the prestack depth migrations was quite significant with improved imaging. The velocity model time anomalies are the results of the truncation of the overlying stratigraphy by the fault throw causing an abrupt velocity contrast across the fault. Seismic rays undergo ray bending and experience traveltime distortions as it propagates across the fault from the overburden low velocity into the high velocity-gradient footwall. This create some non-hyperbolic reflections which will frustrate poststack migration efforts. The poor images in poststack time migration implies that events are migrated to their incorrect positions in vertical time with a Dix-based RMS velocity transformation that is suboptimal. The inadequacies of poststack migrations in perfectly imaging footwall reflections can also be attributed to the dip-dependence effect of normal moveout velocities. NMO and stacking of events along hyperbolas without prior dip moveout correction will cause apparent disruptions and smeared reflections. A better imaging solution is obtained from the prestack depth migrations which showed improved footwall reflections without seismic artifacts. In conclusion, fault shadow is a velocity and wave propagation problem and requires good understanding of the faulted environment and velocities.

Introduction

Fault shadows mostly occur in steeply dipping complex geologic structures like the flanks of subsalts and in the footwalls boundary faults created by shale diapir. Typical examples of reported cases are in the boundary fault of South Texas and the Gulf of Mexico, Tertiary graben of onshore Poland , the permafrost region of Siberia (Stuart, 1999), and the regressive delta in the Gulf of Guinea (Schultz, 1999). Using the PSPI method proposed by Gazdag and Sguazzero for handing strong velocity gradient (Ferguson and Margrave 2005), we investigate the results of poststack and prestack migration of the footwall reflector with the aim of identifying and resolving fault shadow in zero-offset synthetic datasets and multi-offset shot records.

Method

Several literatures exist on the theory of finite difference and phase-shift-plus-interpolation as well as the basic concept of time and depth poststack and prestack migration which will not be discussed in this paper. The methodology in this study can be broadly categorized into five stages namely, model building from sonic log, zero-offset exploding reflector post stack migration and common-midpoint poststack time and depth migration, prestack depth migration and lastly, iterated migrations. Only migrated results obtained from the cross-correlation imaging condition will be discussed.

Results

The two way time conversion in figure 1 of the depth-velocity model reveals time distortion which appear as time sags and pull up. The overburden effect across fault coupled with the high velocity gradient in the model layering introduce anisotropy which cause seismic waves propagating through this interface to undergo some sort of ray bending and traveltime distortion seen by the traced rays (figure 2). The time distortions are confined to the region below the truncation in the footwall. The pull up effect can be seen in the vicinity of each fault truncations of the footwall while the sags are in-between consecutive fault truncations. The mispositioning of the stratigraphy in time is due to the positioning error of depth to time transformation of the bent image ray to a wrong vertical time.

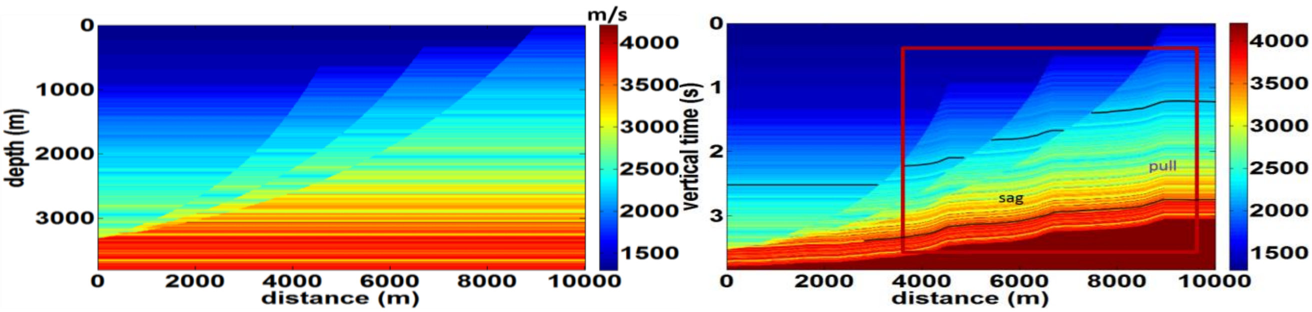

FIG.1. (Left) True geologic model (top) and two-way time velocity model and (right) obtained from depth to time computation. Time distortions behind the fault extends into the footwall of faults and appears as time pull up and sags.

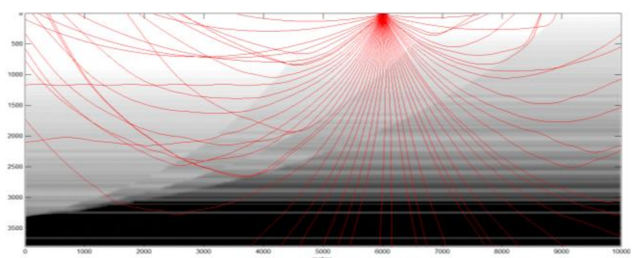

FIG.2. Raytracing of shoot rays into the model.

Migration with true model

The exploding reflector model migration result and post stack time migration result in figure 3a show that time migration is able to image the section of the hanging wall not in the shadow of its neighbouring fault, but extremely limited in imaging the footwall as seen by the distorted reflections. Fault shadow time anomalies are subtle typically in tens on milliseconds. The poststack migration is near if accurate NMO and DMO corrections are applied. The VTI layering of the model and the presence of fault will introduces anisotropy and creates non-hyperbolic moveout which may cause classic NMO correction to fail. The exploding reflector time migrated section is much better than its' cmp-poststack as we would expect because the CMP-stack is not perfectly a zero offset section compare to the normal incident reflection of the exploding reflector model. Furthermore, without the knowledge of fault shadows on seismic datasets, it is easy to misinterpret the distorted footwall reflectors seen on the migrated section in figure 3 as another subseismic fault with conflicting dip or as a back to back fault. Another factor why the footwall reflectors in common-midpoint time migration is severely distorted is because RMS velocity is severely limited by the image ray characteristics of ray bending as it travels from the overburden through fault truncations.

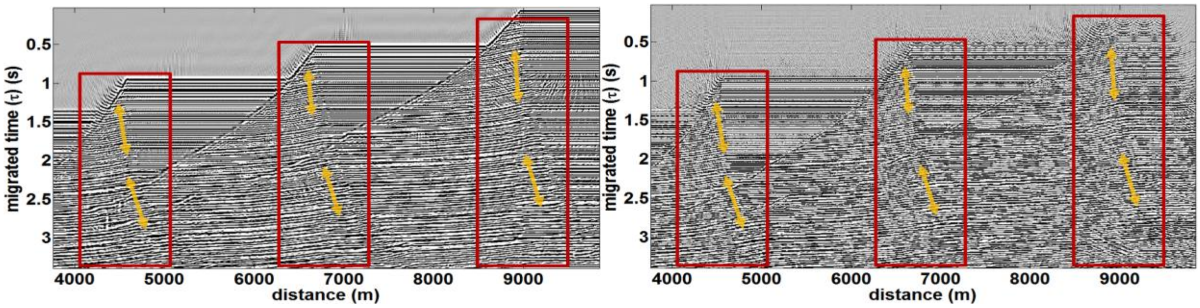

FIG.3. (left) Poststack time migration of exploding reflector model and (right) Poststack time migration of common midpoint stacked section

The results form depth migrations (figure 4a and 4b) are fairer than those obtained from poststack time migrations. Common midpoint poststack depth migration gave the most distorted footwall image in this section. The reasons are not farfetched. For CMP stacking, we normally assume hyperbolic moveout. In the presence of lateral velocity variations at the fault truncations and as well as the presence strong velocity gradient of the layer velocities, the hyperbolic assumptions may not hold. The assumption that a conventional stacked section is equivalent to a zero-offset section is also violated to a varying degree in the presence of dipping faults (Yilmaz, 2001).

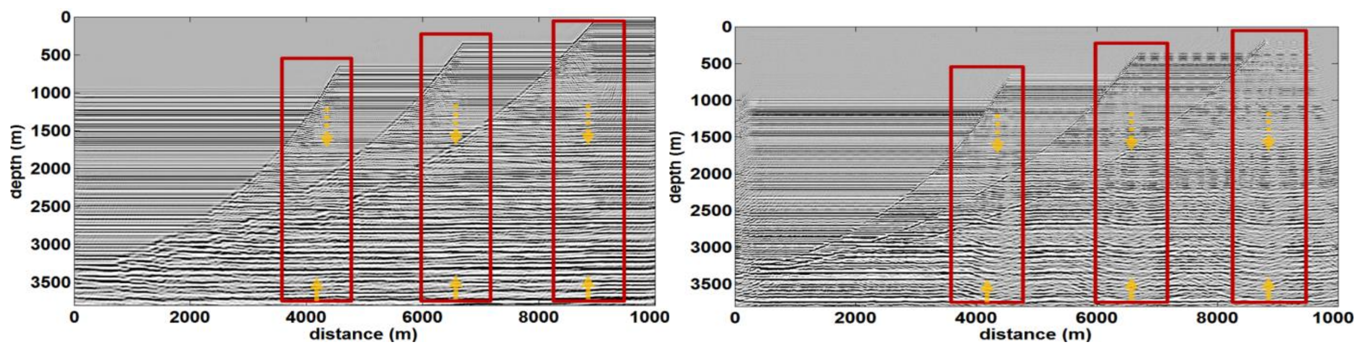

FIG.4a. (left) Poststack depth migration of exploding reflector model with true velocity and (right) Poststack depth migration of common midpoint stacked section with true velocity.

When velocity variation give rise to reflections with non-hyperbolic moveout, time imaging and poststack depth imaging will fail behind the faults. Figure 13 shows that prestack depth imaging resolve aspects of the structure beyond the reach of poststack depth imaging. This anomaly is the cause of the "smiles" in the common midpoint depth migration shown in figure 4a. An improved imaging is obtained from the prestack depth migration (figure 4b) which showed improved and continuous footwall reflections without seismic artifacts.

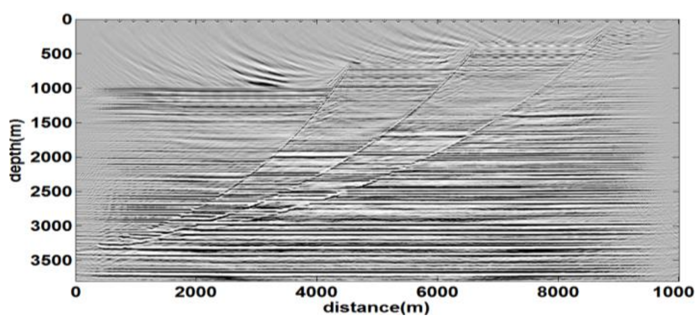

FIG.4b.Prestack depth migration with true model

Iterated migration with approximate model

In most real scenarios, the true velocity is unknown. Migrating with suboptimal velocities will produce even poorer image as seen figure 6 below. Figure 6 shows the post stack and prestack depth migration obtained using the final migration velocity in figure 5 obtained from several iterations and fault constrained picks.

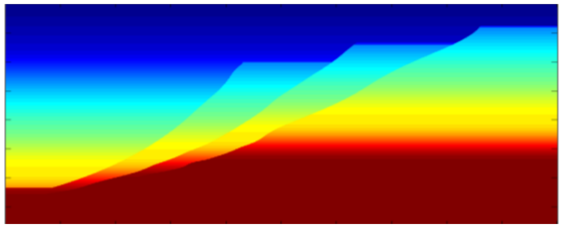

FIG.5. Final iterated velocity model obtained from iterative migration and fault constrained picking.

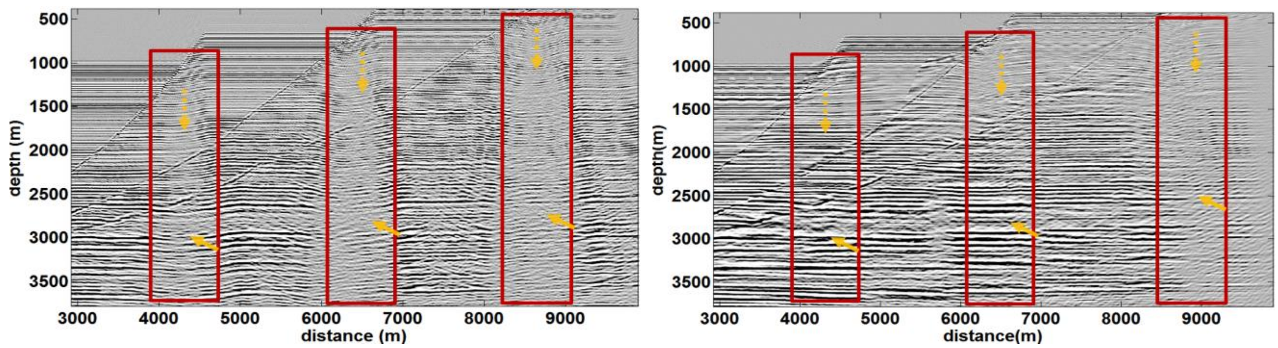

FIG.6. (left) Iterated poststack depth migration and (right) Iterated prestack depth migration with fault constrained velocities

We can see from the iterated poststack depth migrations that poststack migration is limited in imaging behind faults. We observed that footwall reflection deteriorates with inaccurate velocity.

Conclusions

The causes of fault shadows and the capabilities of poststack and prestack migration in imaging listric faulted geology has been looked into from a 2D seismic modeling view point. The following conclusions can be drawn: Shadow zones should be expected in faulted geology where fault termination occurs in areas of strong velocity gradient. The low illuminations in the footwall are more evident with incorrect migration velocities, this confirms the hypothesis that fault shadow is majorly a velocity problem. This makes seismic processing which depend on moveout assumptions to fail. Lastly, we can see that prestack depth migration is far more promising in handling imaging challenges associated with faults than poststack depth migration. In the future, we will build a more geologically consistent fault model, and stretch the capability of depth migration in migrating footwall reflection using an effective migration velocity model in a more realistic scenario. We will also incorporate seismic attenuation and anisotropy.

Acknowledgements

The authors will like to thank CREWES sponsors for their financial support to this research.

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