3D acquisition realities and processing strategies in mountainous thrust areas

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Abstract

The inherent structural complexity of thrust plays makes them ideal candidates for 3D seismic imaging. However, there are many practical constraints placed on the acquisition of 3D data in the mountainous terrains typically associated with thrust regimes. Financial considerations can result in tradeoffs between a desired acquisition geometry and that which is practical. Topographic relief can also impose irregular geometries. Such factors create challenges to the formation of a valid 3D seismic image. Therefore, the realities of acquiring data in mountainous areas must be coupled to the appropriate processing strategies to yield an optimal result.

3D Acquisition

The goal is adequate illumination of the subsurface to obtain sufficient quality to define desired reservoir characteristics, not just structure. Therefore, wide-azimuth designs with adequate migration aperture are desirable. These topics have been well covered in the literature. Another critical component is acquiring single-(point) source and single-receiver geometries to avoid attenuating steeply-dipping signal with surface arrays. Figure 1 shows the impact of wide-azimuth acquisition (left) compared to narrow-azimuth (right).

Short Arrays and Prestack Coherent Noise Attenuation

Rugged topography is typical of thrusted environments. Therefore, to reduce the filtering action of the receiver array on primary data, it is common practice to use single sources. This preserves the nature of the coherent noise, such as azimuthal variations in the noise. Therefore, data-adaptive methods are preferable for robust noise attenuation.

One solution to the coherent noise suppression problem is an f-x domain technique that derives a least-squares estimate of the coherent noise from the data within a user-defined range of dips. The modeled noise may then be subtracted from the shot record. In practice, shot records are binned into azimuth ranges and then grouped by increasing offset. Each azimuthally-ordered record is individually analyzed for coherent noise. Figure 2 (left) is a shot record showing the 11 azimuth bins (12.5-degree increment) with the greatest cross-line orientation. The sudden jumps in the mute pattern correspond to gaps in the offset sampling. Here, a range of dips was defined that spanned the steeply-dipping noise visible on the records. Figure 2 (middle) shows the least-squares estimate of the coherent noise within the specified dip range. The amount of coherent noise present in the data appears greater than a casual inspection of the shot records would initially indicate. Finally, Figure 2 (right) is the shot record with the coherent noise subtracted.

Near-surface Velocities and Long-period Statics

Industry practice has shown that classic delay-time

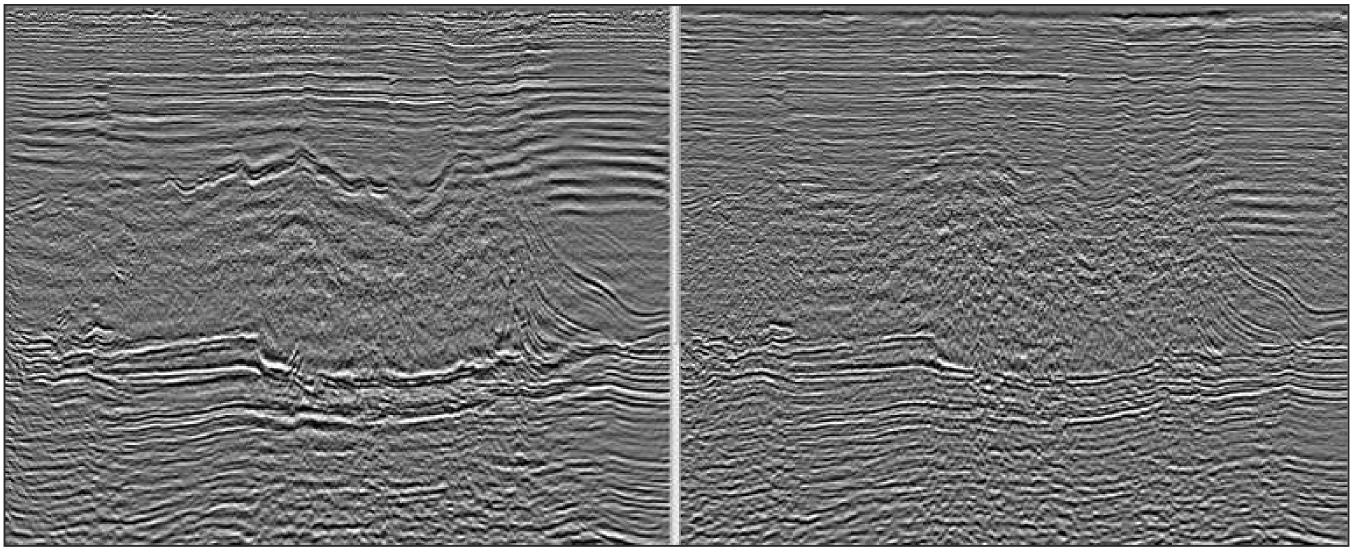

Fig. 1: Wide-azimuth acquisition (left), Narrow-azimuth acquisition (right). Note better reflectivity with wide-azimuth data.

refraction-statics solutions are robust, but they are not robust in the presence of near-surface complexity. Refraction-tomography solutions have shown to yield more refined solutions. Additionally, refraction-tomography solutions are being used as the basis for the shallow component of the initial velocity model used for prestack depth migration (PSDM). Figure 3 (right) shows a refraction-tomography solution and 3 (left) a delay-time method. The refraction-tomography solution (right) shows great coherency.

Topography and Datuming

Thrust regimes are typically associated with mountainous terrains. However, many steps in processing involve placing the data at a horizontal datum. These datuming steps are typically implemented by vertical time shifts. Unfortunately, one of the least appreciated aspects of seismic data processing is the deleterious effect of using such vertical time shifts to perform datum corrections. This is especially true when wave-equation based methods such as DMO and migration are involved. The reason is quite simple; seismic waves do not propagate as vertical shifts. Therefore, distortions are introduced to the data that are inconsistent with the wave-equation methods to follow. The results can be unpredictable.

Fortunately, methods of datuming seismic data that honor the wave equation are available (Berryhill, 1979, MacKay, 1994). Such methods may be efficiently implemented in the processing flow and eliminate potential distortions on the final seismic image. Figure 4a is the migrated result of data shifted from the recording surface (shown dashed) to the datum (at 0 seconds). In the case of Figure 4a, a wave-equation based datuming approach was used and the results are accurate. Figure 4b shows the results of migration after a datum shift using vertical time shifts. Notice the false structural picture that results.

Data Regularization

Understanding the amplitude and phase characteristics of a reflector is often vital for prospect delineation. Therefore, the acquisition geometry should not affect the results of an important step in imaging such as migration. Therefore, 5D data regularization is an important method for mitigating irregular geometry impact such as acquisition footprint and the generation of noise during migration.

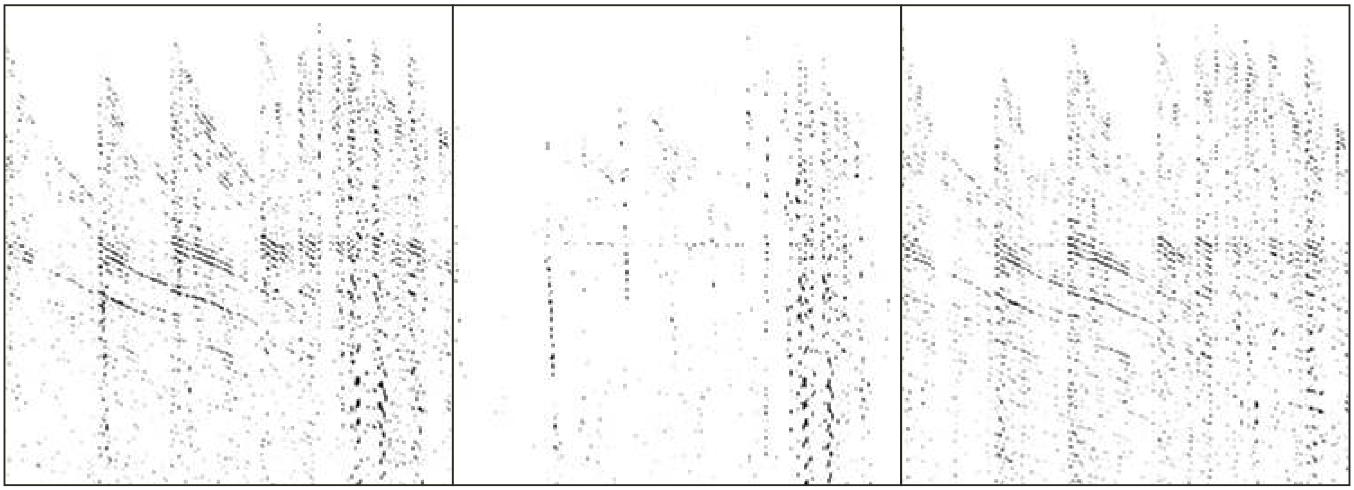

Fig. 2: Azimuth-sorted shots (left). F-X Coherent Noise estimate (middle), Output data (right).

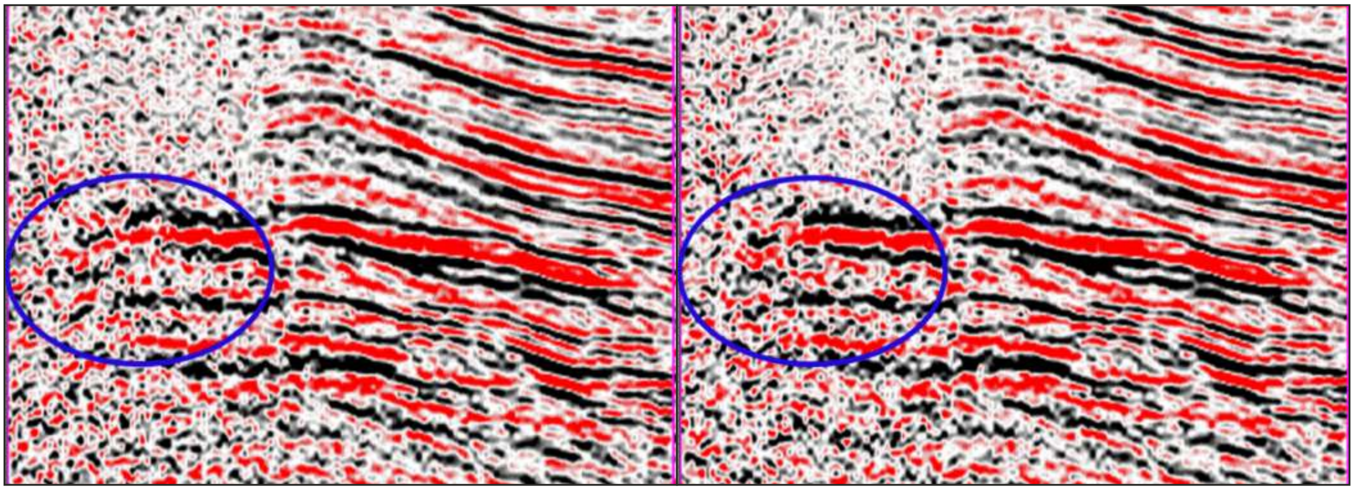

Fig. 3: Delay-time refraction statics (left), refraction tomography (right).

Depth Imaging

Thrust regimes are typically associated with mountainous terrains. This implies complex waveform interactions and, typically, extreme lateral velocity variations. The standard for depth migration is Kirchhoff Prestack Depth Migration. This method uses ray-theory approximations and cannot use multi-arrivals of waveforms to create an image. Reverse-time migration (RTM) is the latest wave-equation methodology that honors extremely complex velocity fields, full waveform

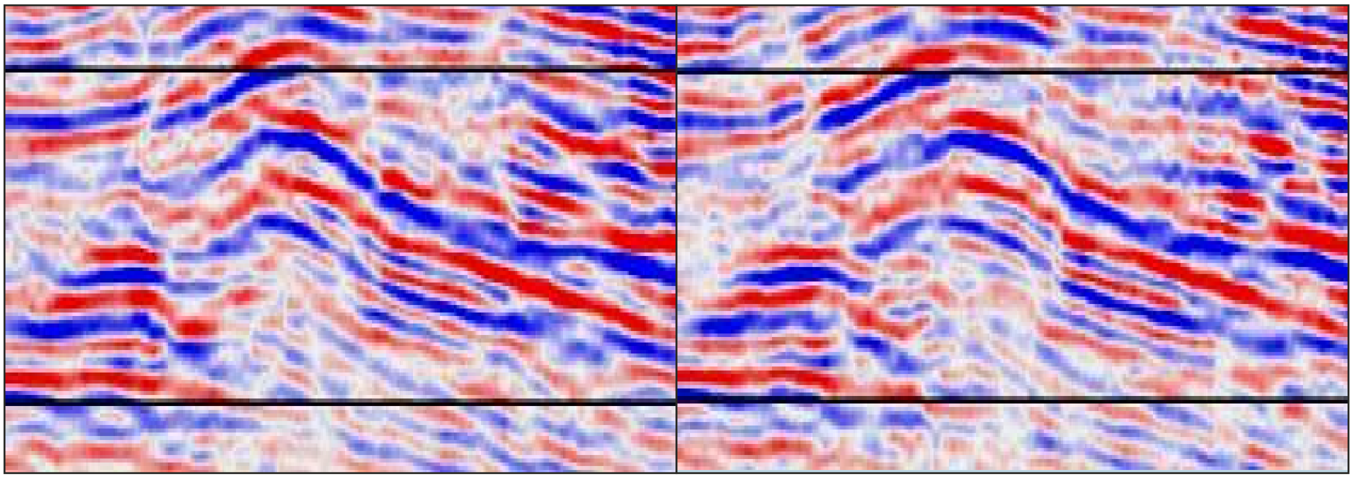
(a) (b)

Fig. 4: Migration from datum (left), migration from surface (right). Note larger structure on right.

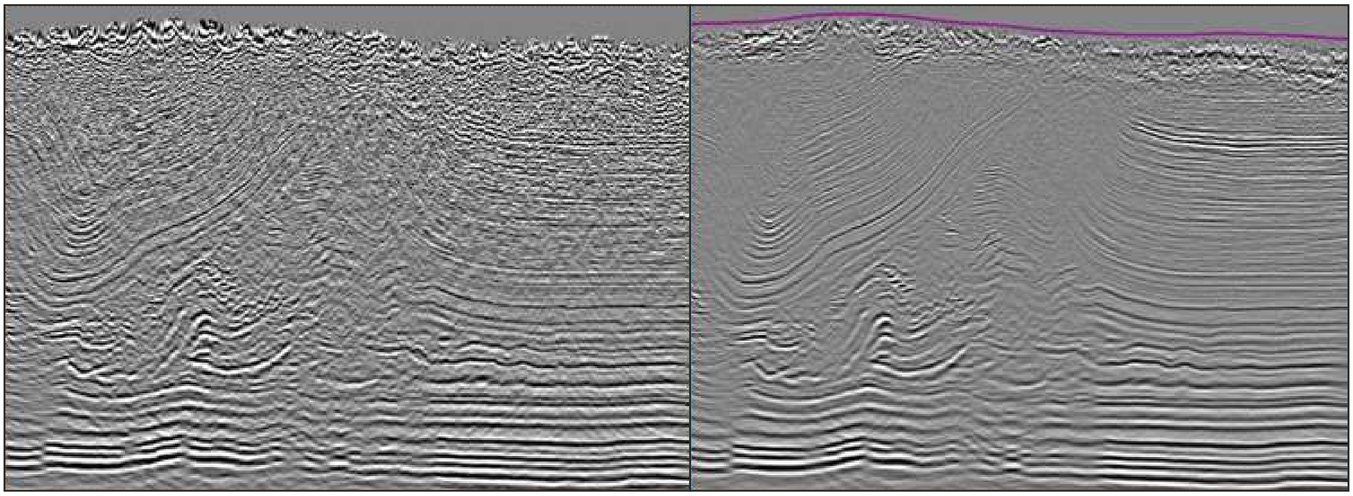
Fig. 5: Migrated field data (left), 5D interpolation (right)

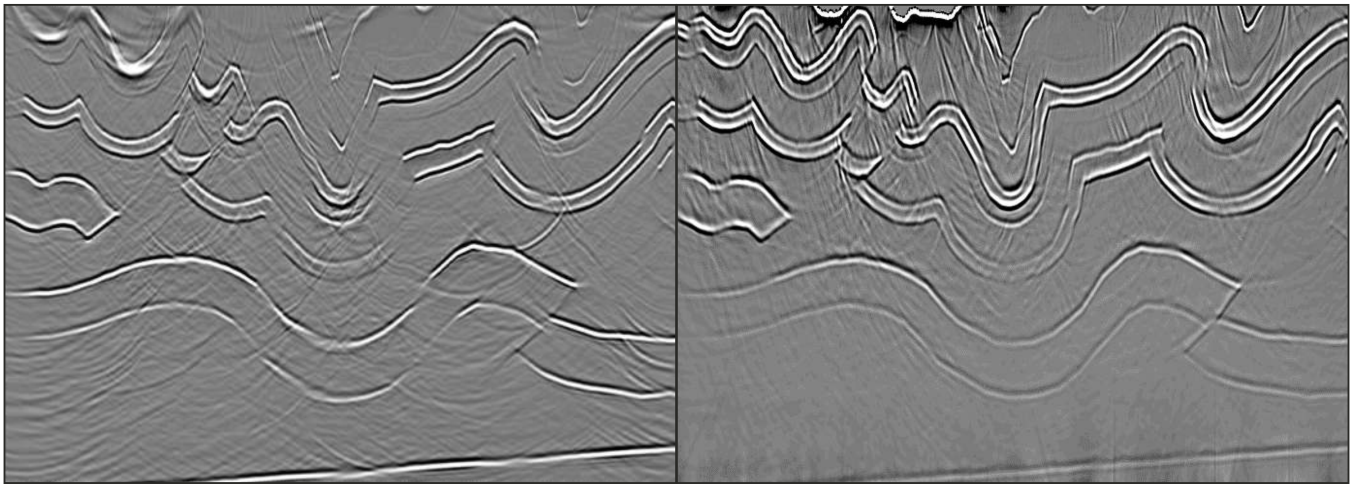
Fig. 6: Kirchhoff PSDM (left), Reverse-time Migration (RTM) (right)

complexity, and it has no dip limits. Figure 6 (left) shows a model example of Kirchhoff migration and (right) shows RTM. Note the overturned thrust geometries imaged with RTM.

Conclusions

Survey design for 3D data is typically wide azimuth, this aids with illumination. Single (point) source and single receiver are optimal for recording both the signal and the noise. Coherent noise, if properly recorded, may be highly attenuated using a noise estimation and attenuation method that accommodates irregular spatial sampling, such as f-x coherent noise suppression. Migration from surface (not a flat datum) is critical for accurate imaging. Indeed, migration from surface has the desirable effect of larger structures. 5D Data regularization can reduce artifacts such as acquisition footprint caused by inconsistent acquisition geometries. The choice of migration algorithms now includes Reverse Time Migration, capable of imaging overturned beds in complex velocity regimes.