The 2D/3D i-cube Workflow for Subsurface Imaging of Complex Structures

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With the i-cube workflow, you circumvent the velocity uncertainty in imaging complex structures, you preserve reflection and diffraction amplitudes, you need not the tedious and time-consuming velocity updating for prestack time migration, and you obtain an improved image in time compared to prestack time migration.

GeoTomo's GeoThrust2D/3D seismic data processing software is now a mature system --- it has been in use by major oil companies, national oil companies, and service companies for more than twelve years. **To provide the GeoThrust user with streamlined solutions, we have constructed two uniquely image-based workflows --- the i-stats 2D/3D near-surface modeling and the i-cube 2D/3D subsurface imaging by using the various modules of GeoThrust.** In this document, we describe the i-cube workflow for subsurface imaging of complex structures.

In areas with complex near-surface with irregular topography and structurally complex subsurface, there is much uncertainty in rms velocity estimation for prestack time migration, whereas interval velocity estimation for prestack depth migration is despairingly challenging. We often attribute the velocity uncertainty to various factors, including strong lateral velocity variations, heterogeneity, anisotropy, and three-dimensional behavior of complex structures. Nevertheless, it is not easy to identify the cause of and account for the ucertainty as it often is a combination of the various factors. And the analyst struggles with much difficulty when estimating a velocity field whether it is for prestack time or depth migration.

Velocity uncertainty invariably gives rise to erroneously high or low migration velocities, which then causes *two* problems with prestack migration: (1) we fail to *preserve reflector amplitudes*, and (2) we also fail to *position the reflectors* correctly and *focus diffractions to their apexes*. We may choose to solve both problems *simultaneously* or *one after the other*. The quality of image-gathers associated with prestack migration may or may not warrant the simultaneous solution. In areas with irregular topography, complex near-surface, and complex subsurface, it may not. What then? **The i-cube workflow, applicable to both 2-D and 3-D seismic data, to solve the two problems with prestack time migration one after the other, which includes synthesis of a zero-offset wavefield to capture and preserve all reflections and diffractions, followed by zero-offset time migration.**

The i-cube Workflow

The i-cube workflow (Figure 1) includes construction of an image volume by prestack time migration of shot gathers using a range of constant velocities. This image volume can be used to pick rms velocities for prestack time migration. Yet, the multiplicity of semblance peaks associated with the image volume remains to be perilous. We can sum the image panels within the image volume over the velocity axis to obtain a composite image in time so as to *preserve* all events in the image volume and avoid committing ourselves inadverdently to a velocity field which most likely would have some uncertainty. This summation strategy, however, works if the events within the volume are stationary in time and space. To meet this requirement, we unmigrate each of the image panels within the image volume and then sum over the velocity axis. The resulting unmigrated section actually is equivalent to a zero-offset wavefield. The final step in the workflow is poststack time migration of the zero-offset wavefield.

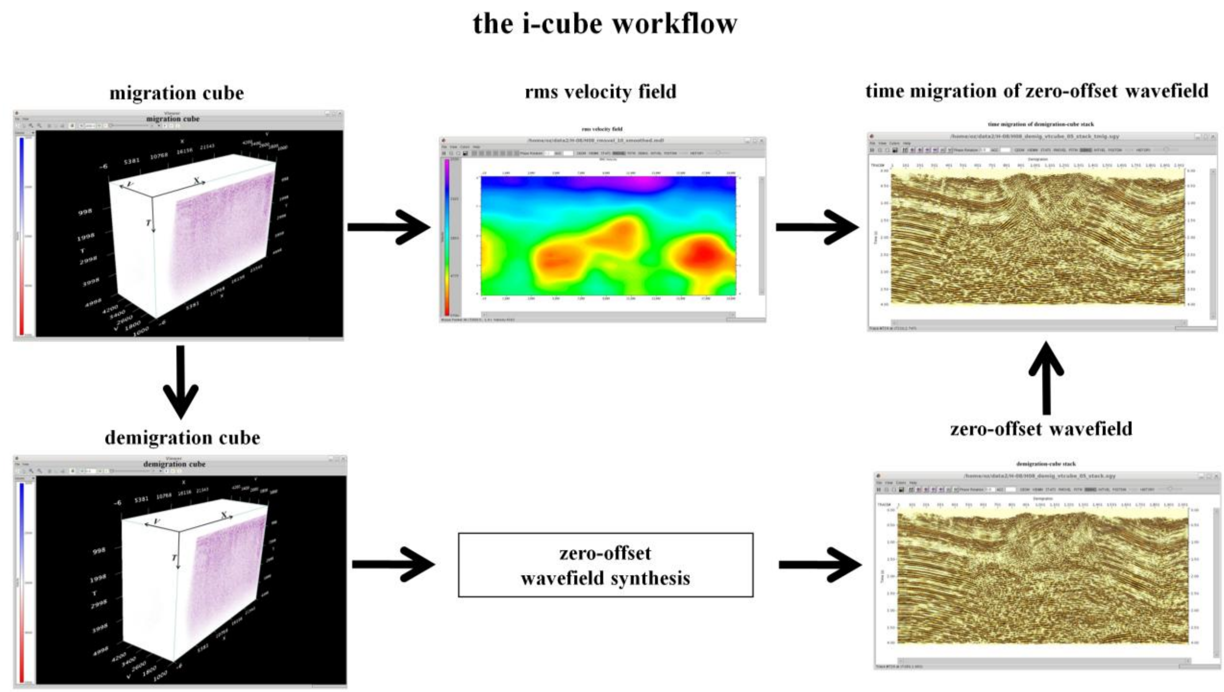

Figure 1. The i-cube workflow: Migration cube is constructed by prestack time migration of shot gathers using a range of constant velocities, whereas the demigration cube is created by unmigrating the image panels of the migration cube with the corresponding constant velocities.

The i-cube Case Study

We demonstrate the i-cube workflow using a field data set from a thrust belt. Figure 2 shows an image obtained by prestack time migration (PSTM) using an rms velocity field that was constructed by velocity picking from the image volume obtained by PSTM of shot gathers using a range constant velocities from a floating datum. The semblance spectrum at location A exhibits distinctive set of peaks that allows picking a velocity function unambiguously (Figure 3a), whereas the semblance spectrum at location B exhibits a multiplicity of peaks that would give rise to uncertainty in velocity picking (Figure 3b). The structural complexity at the central portion of the line observed in Figure 1 is indicative of the difficulties in velocity picking. A further evidence of the troubling nature of velocity uncertainty is provided by the common-image-point (CIP) gathers associated with the PSTM. The CIP gather at location A (Figure 3c) exhibits flat events that confirm the accuracy of the rms velocity field used for PSTM, whereas the CIP gather at location B (Figure 3d) exhibits highly complex and interfering events --- again indicative of the velocity uncertainty within the structurally complex portion of the line. This CIP gather not only is a manifestation of the structural complexity resulting in a poor image (Figure 2), but also is practically unusable for velocity update based on flatness of events, nor can it be used for verification of the accuracy of the rms velocity field used for PSTM.

This leads us to the following question: Can we *circumvent* the velocity uncertainty rather than hopelessly struggle to *eliminate* it and produce an image in time better than obtained by conventional PSTM? The i-cube workflow provides an answer to this question in the positive.

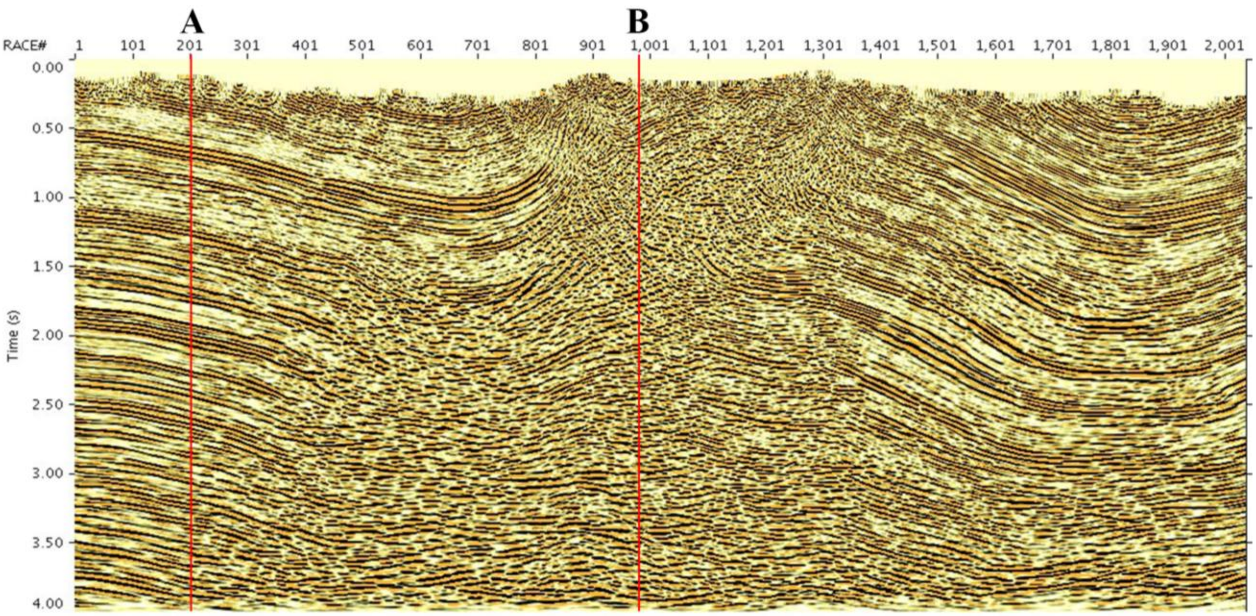

Figure 2. An image section obtained by prestack time migration (PSTM) from a thrust belt. The rms velocity semblance spectra and common-image-point (CIP) gathers at locations A and B are shown in Figure 2.

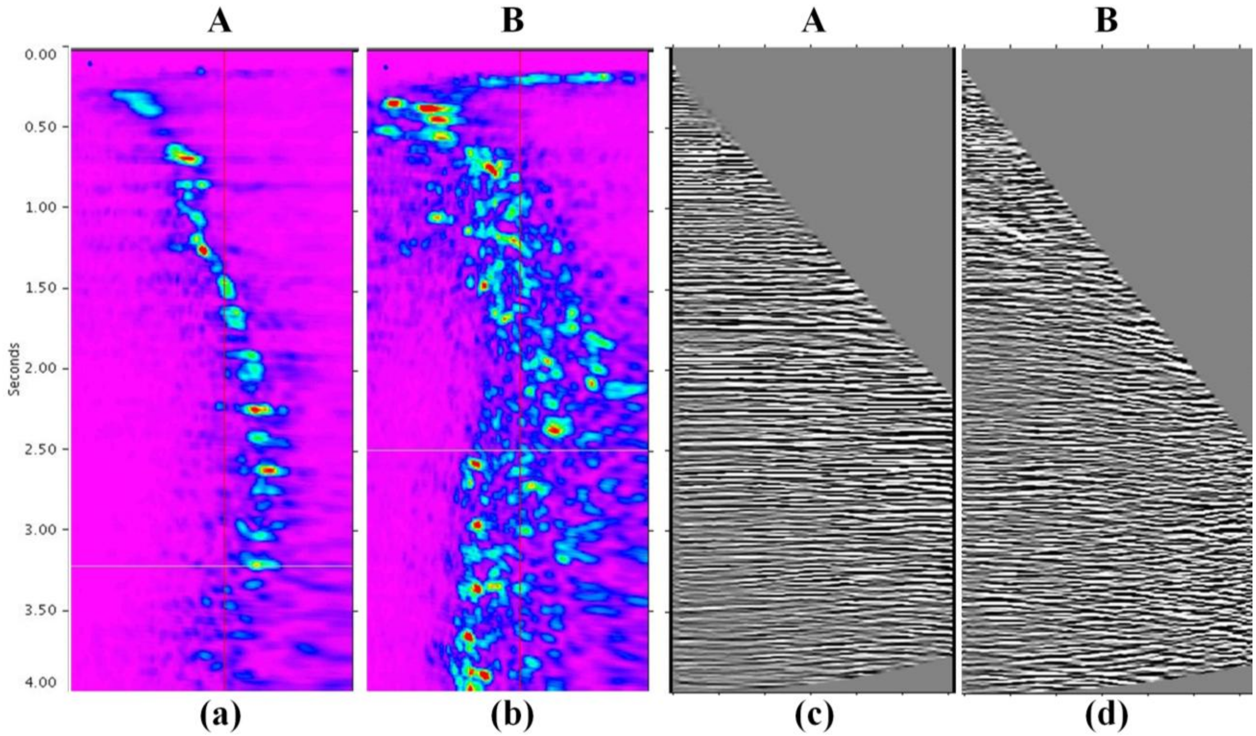

Figure 3. The rms velocity semblance spectra (a) and (b), and CIP gathers (c) and (d) at locations A and B shown in Figure 2.

In the presence of conflicting dips with different stacking velocities, conventional CMP stack is not equivalent to a zero-offset wavefield. Within the context of subsurface imaging in time, this is the compelling reason for doing prestack time migration in lieu of poststack time migration, aside from the fact that the former also is used for rms velocity estimation and updating based on the flatness of events in CIP gathers. We can obtain the zero-offset wavefield by PSTM followed by demigration of the resulting image. However, this implies a commitment to an rms velocity field for PSTM, which may have much uncertainty. The i-cube workflow (Figure 1) enables to synthesize a zero-offset wavefield without the commitment to an rms velocity field so as to circumvent velocity uncertainty. The zero-offset wavefield synthesis (Figure 3) is achieved by summation over the velocity axis of the demigration cube (Figure 1) so as to *preserve all reflections and diffractions* and avoid committing ourselves inadverdently to a velocity field which most likely would have some uncertainty. This zero-offset wavefield can then be time-migrated using the rms velocity field picked from the migration cube to obtain the image as shown in Figure 4. So long as we have preserved the reflection and diffraction amplitudes by the zero-offset synthesis, time migration of this zero-offset wavefield can be repeated as many times desired to secure correct positioning of the reflectors. In contrast with rms velocity updating by repeated prestack time migration, this exercise requires virtually negligible effort.

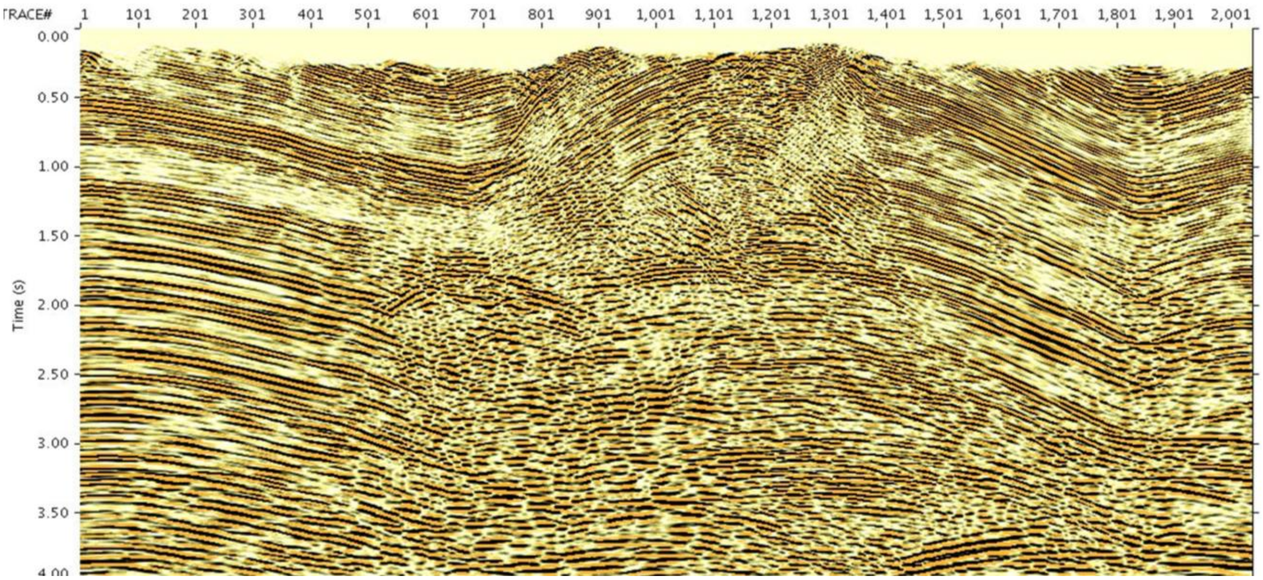

Figure 3. The synthesized zero-offset wavefield obtained by summation of the image panels of the demigration cube.

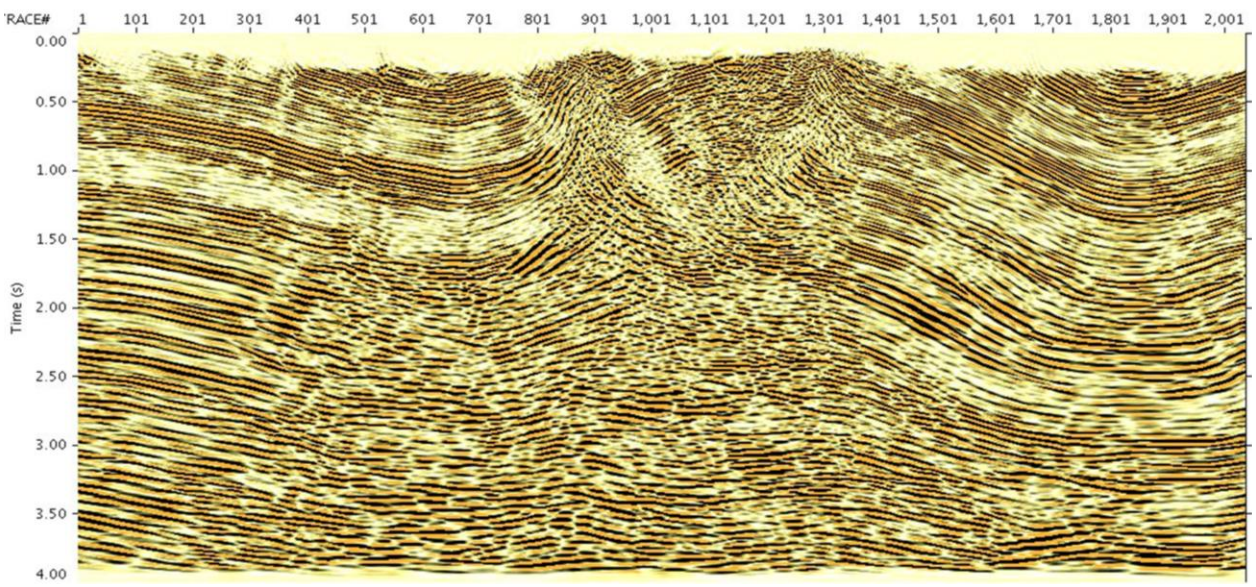

Figure 4. Poststack time migration of the synthesized zero-offset wavefield shown in Figure 3. This is the *principal image* in time that can be used for structural interpretation. Compare this image with the image obtained by PSTM shown in Figure 1 obtained by using the same rms velocity field, and note the significant improvement of the structural complexity in the central portion of the line.

Conclusions

The i-cube workflow essentially involves a transformation from the observation domain (field records) to the zero-offset domain (the demigration, or zero-offset, volume described in Figure 1) to preserve reflections and diffractions. Rather than struggling to *eliminate* the uncertainty in velocity estimation for PSTM completely --- an impossible task, the workflow *circumvents* the velocity uncertainty. Because events in the zero-offset volume are stationary both in time and space, we can sum over the velocity axis to synthesize a zero-offset wavefield so as to preserve all events contained in the volume and avoid committing ourselves inadverdently to a velocity field which most likely would have some uncertainty. The synthesized zero-offset wavefield can then be migrated by poststack time migration. The resulting image would have all the events, albeit some may be mispositioned because of velocity errors. The poststack time migration, however, can be repeated using a revised rms velocity field to position the events correctly. If, on the other hand, an rms velocity field with much uncertainty is used for PSTM, the resulting image not only would have mispositioned events but also some events with incomplete focusing or missing altogether. To remedy both the problems of event mispositioning, incomplete focusing, and missing events, velocity field would have to be updated and PSTM would have to be repeated --- a formidably time-consuming and resource-driven exercise, especially in case of 3-D imaging. In contrast, the i-cube workflow produces a synthesized zero-offset wavefield that preserves reflection and diffraction amplitudes, and only requires poststack time migration that can be repeated at much less cost.