Accurate imaging of complex salt features with narrow azimuth migration

M.M. Fliedner, S. Crawley, D. Bevc (3DGeo Development Inc.) & B. Biondi (Stanford University)*

Summary

Because of speed and easy availability of common image gathers common-azimuth migration is an attractive alternative to shot profile migration. Its limitations in the presence of strong reflection azimuth migration can be removed by using a narrow-azimuth approximation without sacrificing the speed advantage. Narrow-azimuth migration achieves the same image quality as full DSR or shot-profile migration. We demonstrate base salt and sub salt imaging improvements with narrow azimuth migration on the SEG-EAGE C3 salt model data set.

Introduction

In mature areas like the North Sea or Gulf of Mexico, getting the most out of old fields requires fast and accurate seismic imaging for reservoir analysis and time-lapse (4-D) monitoring. Whereas shot-profile migration fulfils the requirements of imaging accuracy, it is also computationally expensive, especially if common image gathers are needed for velocity analysis. Survey-sinking (DSR) methods optimized for towed-streamer geometry such as common-azimuth or narrow-azimuth methods (Biondi and Palacharla, 1996; Bevc and Biondi, 2003) are therefore an attractive alternative to SPM.

It can be mathematically demonstrated that shot-profile (SPM) and survey sinking downward continuation (DSR) are theoretically equivalent (Wapenaar and Berkhout, 1987, Biondi, 2002; Bevc et al., 2003). This means, that properly implemented, the two methods should yield equivalent accuracy and comparable imaging results. The common azimuth (ComAz) approximation to the full azimuth implementation of survey-sinking or double- square root (DSR) migration takes notice of the fact that most marine data are acquired in streamer geometry that is very nearly zero azimuth, or can be easily corrected to zero azimuth using an azimuth moveout (AMO) operator (Biondi et al., 1998). This results in a 4-D downward continuation that is extremely efficient, and is orders of magnitude faster than the equivalent 5-D downward continuation that does not take into account the streamer geometry and the common azimuth approximation. For areas where the common azimuth (ComAz) approximation may be in question, we use a narrow azimuth (NarAz) formulation by including crossline offset wavenumbers in the downward continuation. The downward continuation propagator applied in ComAz and NarAz is commonly a form of the extended split-step method or the generalized screen propagator. Properly applied, these propagators are capable of imaging steep dips in the presence of strong lateral velocity variations.

Aside from the significant (order of magnitude) speed issue, ComAz and NarAz have substantial advantages in terms of the ability to generate angle gathers at almost no additional cost for migration velocity analysis and residual moveout (Liu et al, 2001).

Common azimuth and narrow azimuth migration

ComAz is based on the observation that marine streamer data are collected along relatively narrow streamer arrays, and makes the assumption that multi-streamer data can be represented by an equivalent (after rebinning or azimuth moveout) data set that is purely zero azimuth. The method further assumes that migrated energy does not rotate in azimuth during the downward continuation process of migration imaging. These assumptions are generally good in practice, but an exception occurs for the case of steeply dipping imaging targets that are at 45º azimuth to the data acquisition geometry. Under these conditions the common azimuth assumptions break down, and the resulting image is degraded.

NarAz addresses this particular issue by allowing the data to retain the azimuth range with which it was acquired. Instead of assuming that the data are all zero-azimuth and are not allowed to rotate during downward continuation, NarAz assumes data are acquired over a narrow crossline azimuth range, and that the data are allowed to rotate over the given azimuth range. When NarAz is implemented to allow an adequate number of crossline azimuths, it will capture all recorded propagation events and image them accurately for a computational cost that is substantially less than that of SPM.

In the following example, all migration algorithms are implemented with the same downward continuation operator (phase shift plus interpolation, PSPI, with multiple reference velocities).

Synthetic Data Example

The SEG-EAGE C3 salt model seismic data set highlights the limitations of the common azimuth assumption in areas with complex salt bodies (Fig. 1): the base salt reflector is not well imaged (red arrows) under narrow top salt canyons and the underlying flat sub-salt reflector is poorly illuminated in this area (yellow arrow). These gaps can only be filled by using the full multiple streamer data (280 m maximum crossline offset). Migration of the full azimuth range (Fig. 2) fills the gaps left by the zero azimuth migration. Note in particular the subtle undulations in the base salt reflector, which are imaged correctly (Fig. 3): these pose a challenge to SPM if shot decimation is used. Another challenge for SPM arises from the narrow canyons in the salt top (blue arrows): DSR migration handles the migration aperture effects due to sparse crossline sampling more easily than SPM. Substantially the same image quality as with full DSR migration is achieved by NarAz (Fig. 4) with its concomitant speedup.

Usually, the migrated image is extracted at zero offset and prestack gathers are not preserved. NarAz migration enables us to compute angle gathers (ADCIGs) fairly cheaply, allowing us not only to do migration velocity analysis, but also to capture seismic energy with rotated reflection azimuth (Biondi and Tisserant, 2004). For the best image, the correct azimuth rotation should be selected from the angle gathers at each depth point, but even a simple stack improves the image resolution.

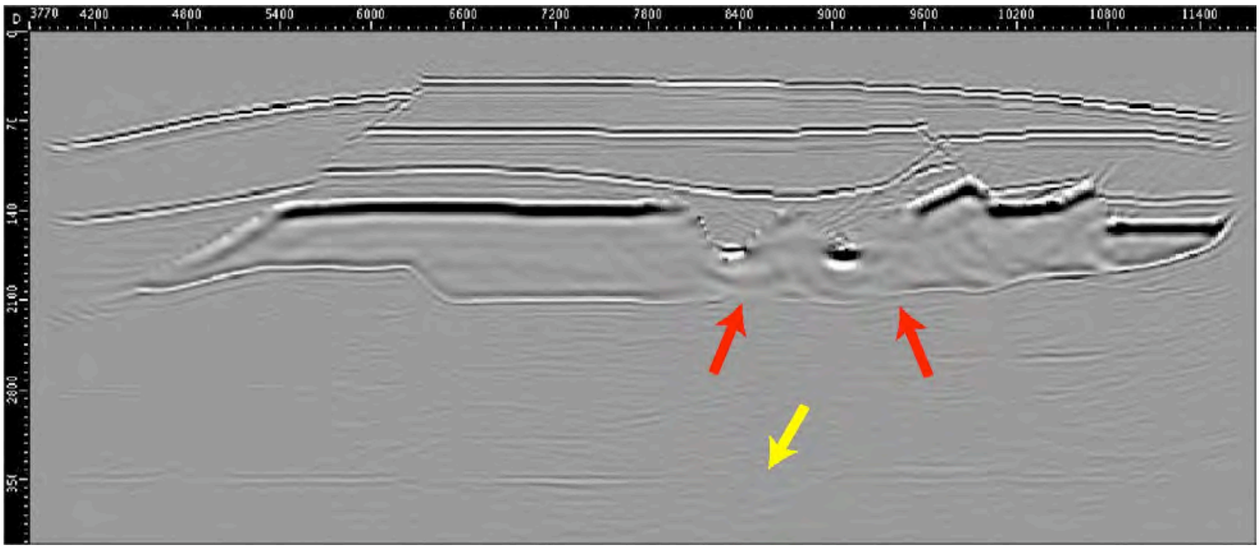

Figure 1: section from common-azimuth migration of SEG-EAGE C3 salt model data

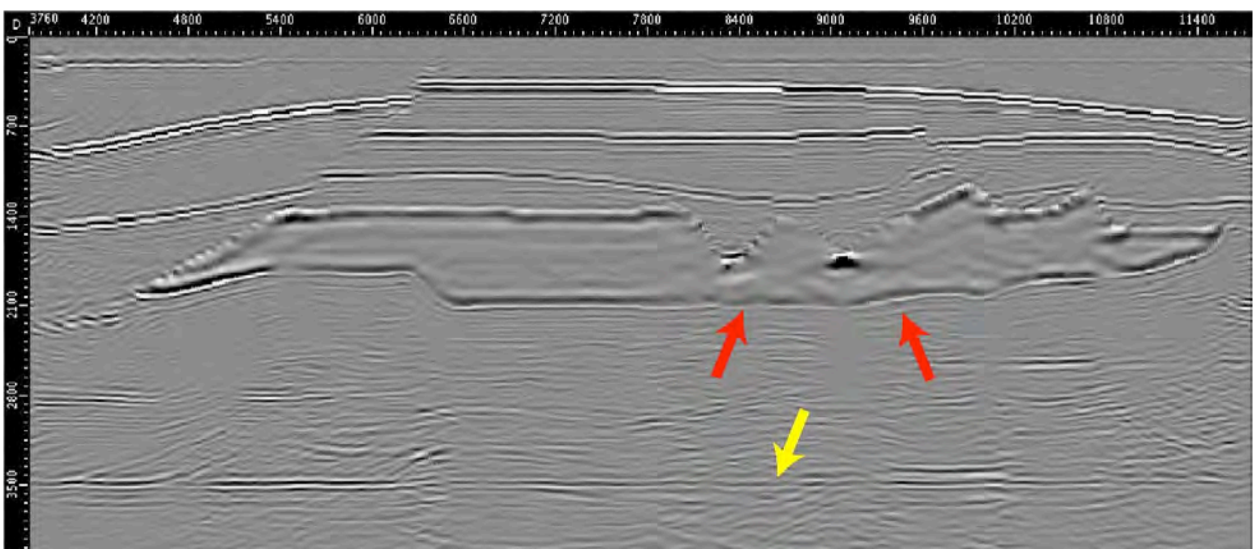

Figure 2: section from full-azimuth (DSR) migration of SEG-EAGE C3 salt model data

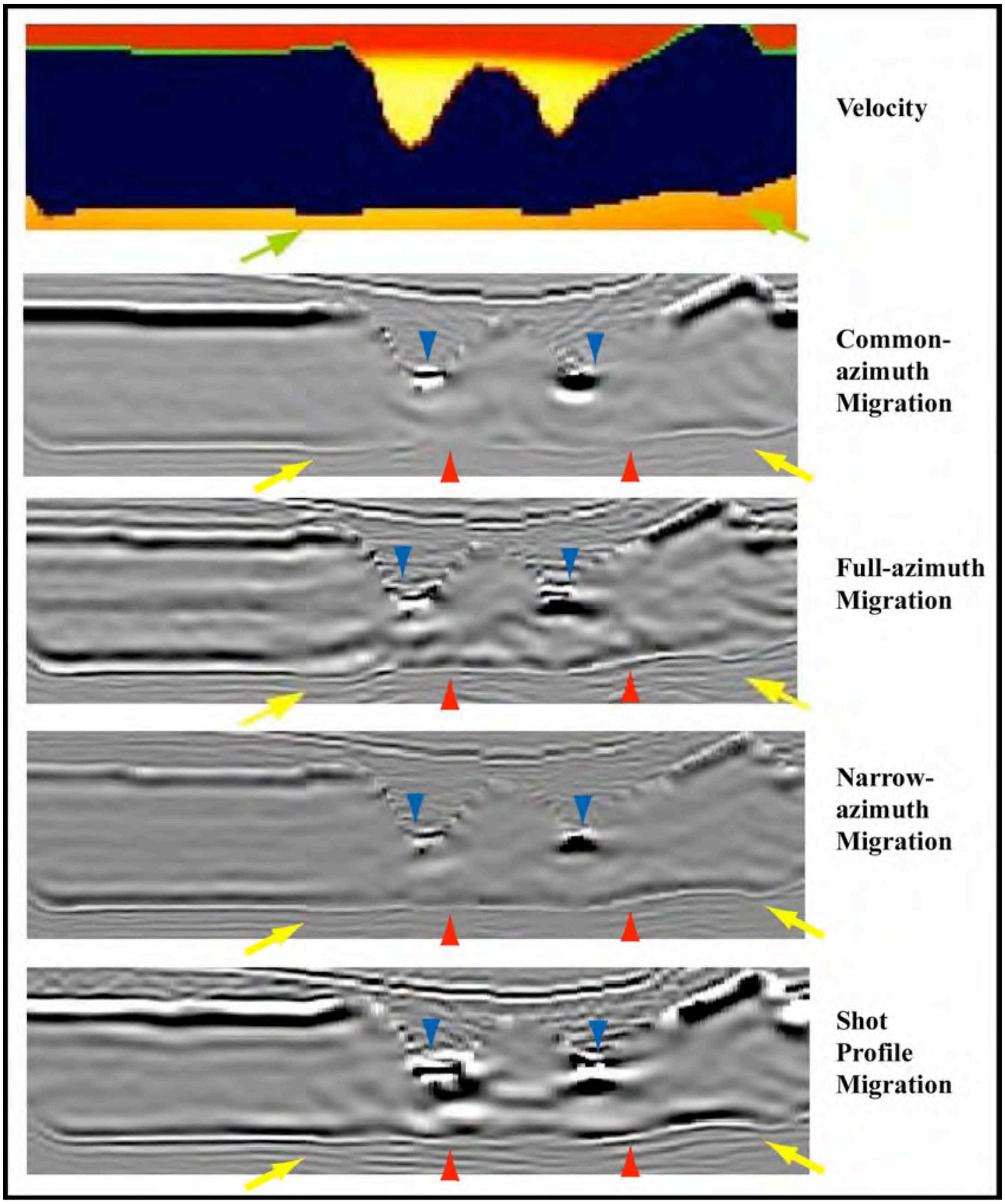

Figure 3: detail from C3 section displaying velocity model and common-azimuth migration in comparison to full-azimuth (DSR) migration, narrow-azimuth migration, and shot profile migration

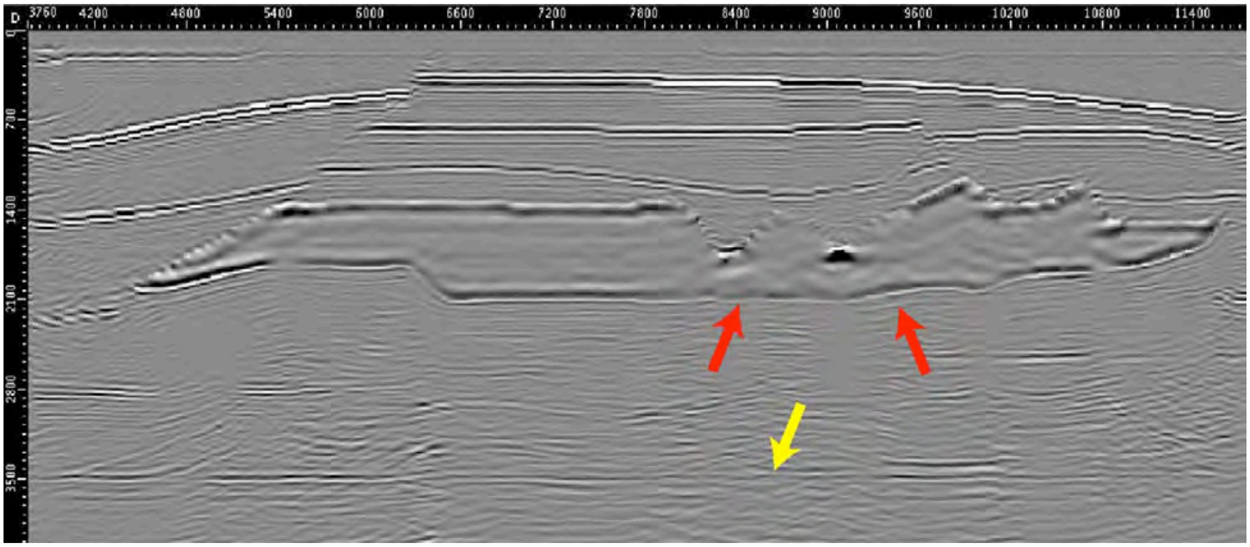

Figure 4: section from narrow-azimuth migration of SEG-EAGE C3 salt model data

Conclusions

Narrow azimuth migration removes the common-azimuth imaging limitation of seismic reflections with strong reflection azimuth rotation and thereby produces images of the same quality as full azimuth DSR migration or SPM, while preserving most of the speed advantages of the common azimuth approximation. This is demonstrated with the improved base salt and sub salt image of the complex SEG-EAGE C3 salt model data set.

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