P004 AN INTEGRATED DATA-DRIVEN APPROACH TO SEISMIC REFLECTION IMAGING

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Summary. The development of new seismic reflection imaging methods is an area of ongoing research. In the course of the years, many techniques such as, e. g., NMO/DMO/stack or prestack depth migration have been established and are routinely applied today. However, with increasing technical and computational resources powerful alternatives to the conventional methods evolved in recent years. Among these is, for instance, the data-driven simulation of zero-offset (ZO) sections with the Common-Reflection-Surface (CRS) stack. With the kinematic wavefield attributes derived during this process, an entire integrated seismic reflection imaging work flow can be established that includes the CRS stack itself, and the use of the wavefield attributes to estimate a velocity model and to optimize the subsequent depth migration. We demonstrate some of the possibilities of CRS-stack-based seismic reflection processing on a synthetic data example.

Introduction. Seismic reflection data processing aims at obtaining the best possible image of the subsurface, either in the time or in the depth domain. Particularly in regions with complex geological structures, this is a challenging task for geoscientists and their processing tools and requires to combine all available geological and geophysical information. A general overview of the main processing steps is given in Figure 1. In recent years, data-driven imaging methods have increasingly gained in relevance. They open up a number of new possibilities in seismic data processing. Here, we want to focus on one of these methods, namely the Common-Reflection-Surface (CRS) stack, and its integration into the seismic reflection imaging work flow. As is shown in the next section, the CRS stack produces, along with a simulated ZO section, several wavefield attribute sections that are useful in further processing: Firstly, these attributes contain kinematic information that can be utilized in a tomographic velocity model inversion. This allows to obtain a smooth velocity model for depth imaging and, thus, helps to establish the link between the time and the depth domain. If required, this model can then be further refined by migration-based velocity analysis. Secondly, the attributes can be used (in combination with the previously determined velocity model) in the depth migration process itself, e. g., to restrict the aperture of Kirchhoff migration operators to optimal values. Following this approach, flexible integrated pre- and poststack processing strategies are available.

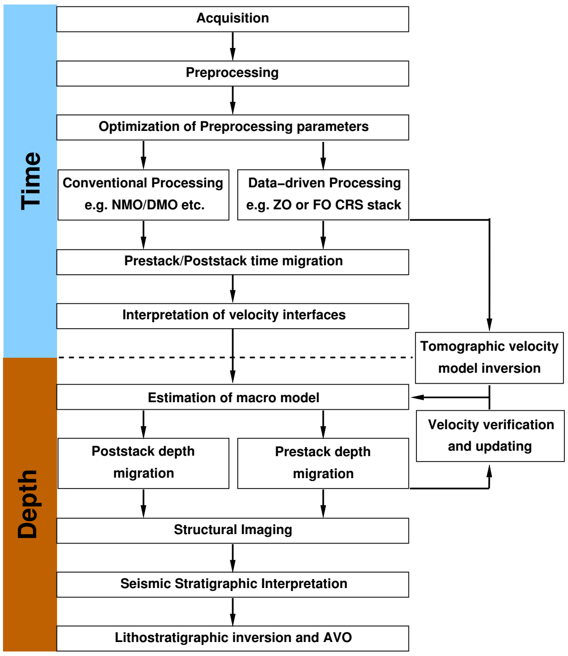

Figure 1: General seismic data processing flowchart [modified after Farmer et al. (1993)].

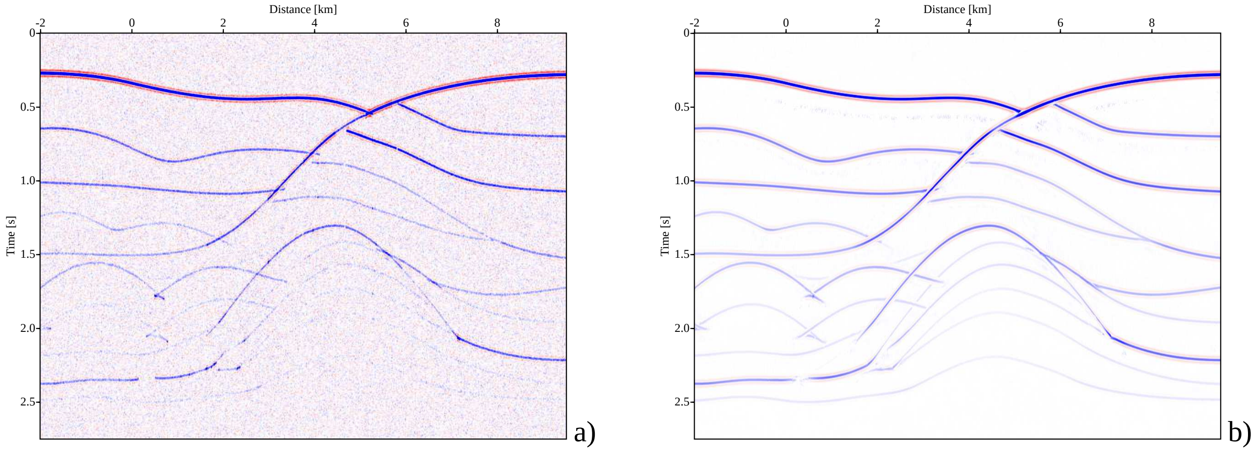

Figure 2: Zero-offset sections a) forward modeled by dynamic ray tracing (without diffraction events) and b) simulated by means of the ZO CRS stack from noisy prestack data.

Common-Reflection-Surface stack. The Common-Reflection-Surface (CRS) stack (see, e. g., Müller, 1999; Jäger et al., 2001) was originally introduced to simulate high-quality ZO sections from prestack data. In addition to the stack itself, the CRS method provides kinematic wavefield attributes that characterize the reflection events in the data. In contrast to conventional ZO simulation methods, the CRS approach fits entire stacking *surfaces* to the events rather than only stacking *trajectories*. As a consequence, far more traces contribute to each simulated ZO sample so that a higher signal-to-noise (S/N) ratio can be achieved even for data of poor quality. The application of the CRS stack is entirely data-based and, thus, does not require an a-priori available velocity model. A synthetic example of a CRS stacked ZO section compared to its modeled counterpart is shown in Figure 2. The input multicoverage data were created by dynamic ray tracing in the blocky model shown in Figure 3a. The CRS stack has also been successfully applied to real data in 2D and 3D (see, e. g., Bergler et al., 2002; Trappe et al., 2001).

The kinematic wavefield attributes obtained with the CRS stack can be used for a number of applications, e. g., to estimate the geometrical spreading factor (Vieth, 2001) and the projected Fresnel zone, and to distinguish between reflection and diffraction events (Mann, 2002). A wavefield-attribute based generalized Dix-type inversion scheme for layered models has been discussed by Majer (2000) and Biloti et al. (2002), whereas a tomographic approach to construct smooth migration velocity models from CRS attributes has recently been introduced by Duveneck and Hubral (2002). This approach will be briefly described below.

Velocity model estimation. The determination of a velocity model is one of the crucial steps in seismic depth imaging. Usually, stacking velocities are used for an initial velocity model. The model is then iteratively updated by repeated prestack migration and analysis of residual moveouts in common-image gathers. This is an expensive and time-consuming process. An alternative approach is reflection tomography, which has the drawback that it requires extensive and often difficult picking in the prestack data. Picking in stacked sections of significantly increased S/N ratio, as are obtained with the CRS stack, obviously simplifies the problem. With the CRS attributes, an approximation of the kinematic prestack response of a reflector element (including the response of the common reflection point) in the subsurface is attached to each picked sample. Thus, the picked traveltimes and corresponding CRS attributes provide sufficient information for the determination of a velocity model. If a smooth model description without discontinuities is used, it is no longer necessary to pick continuous events over successive traces. A model that is consistent with the picked data (CRS attributes at a number of locations in the simulated ZO section) is found with an iterative tomographic approach. Details of the method can be found in Duveneck and Hubral (2002).

An example of such a smooth velocity model, derived from CRS attributes picked in the ZO section shown in Figure 2b, is displayed in Figure 3b. The original velocity model is shown for comparison in Figure 3a. The migration result (Figure 4) indicates that the determined velocity model is kinematically correct. In the

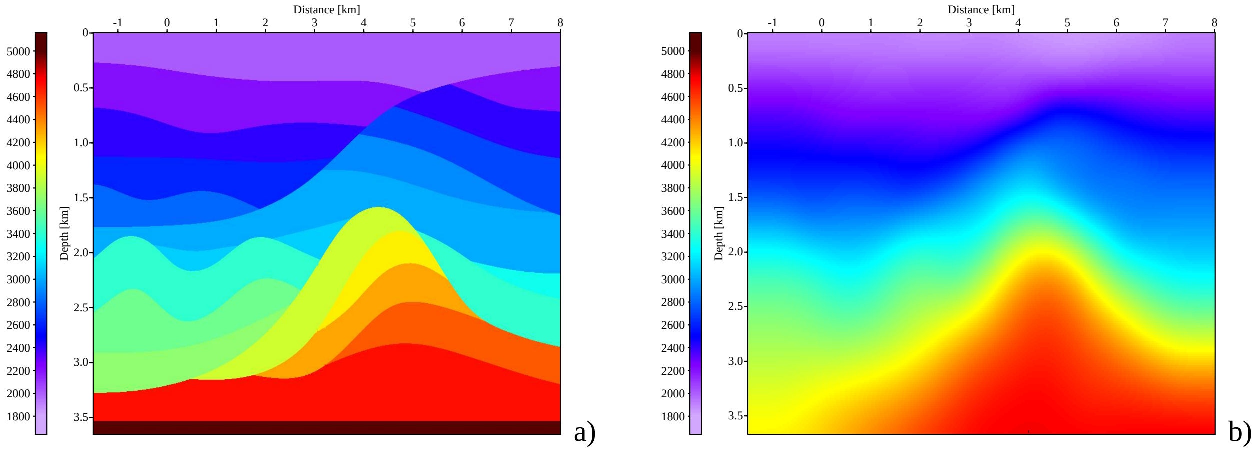

Figure 3: a) part of the true blocky velocity model corresponding to the inversion target zone; b) smooth velocity model estimated by means of tomographic inversion using CRS stack attributes. Colors denote P-wave velocities in m/s.

case of very complex velocity distributions, the smooth velocity model obtained with CRS attributes can be used as a start model for a detailed migration-based velocity analysis.

Depth migration. Apart from the migration velocity model obtained with the above described approach, ray-based migration processes themselves can benefit from the CRS attributes: Vieth (2001) used data-derived emergence angle information to increase the efficiency of depth migration. In general, it is possible to apply the attributes for a limited-aperture Kirchhoff depth migration where the stacking is then only performed in the vicinity of the stationary point within the projected Fresnel zone. This significantly reduces the computational costs and the migration noise while still allowing the correct handling of amplitudes (Schleicher et al., 1997; Sun, 2000). Figure 4a depicts the prestack depth migration result of the synthetic multicoverage data using the reconstructed smooth velocity model shown in Figure 3b. The original prestack dataset contains offsets up to 2000 m. To avoid distortion of shallow reflectors, only offsets up to 1000 m were stacked to obtain Figure 4a. Note that in the shown result the previously derived ZO CRS attributes were not utilized to limit the aperture. For a good approximation of the projected Fresnel zone in prestack migration, additional CRS attributes for the finite-offset case would be required. However, the finite-offset CRS stack was not performed for this example as our primary goal was to test the reconstructed velocity model. Figure 4b shows the common-image gather at $x = 4200$ m. Obviously, most events are flat and no additional migration-based model refinement was applied.

Conclusions. We have demonstrated that the CRS stack and the associated kinematic wavefield attributes can be used in seismic imaging applications which go far beyond the purposes for which the method was originally designed—the simulation of ZO sections with significantly improved S/N ratio. The kinematic wavefield attributes contain information that can be used for the estimation of migration velocity models. In addition, they can be applied to determine projected Fresnel zones and increase the efficiency of Kirchhoff depth migrations. Apart from the applications discussed here, the CRS stack has potential in other seismic processing topics such as static corrections or redatuming. Together with other recently developed extensions of the CRS stack (3D ZO CRS stack, 2D finite-offset CRS stack, and CRS stack allowing for topographic variations), imaging can be performed with a variety of case-specific strategies. In particular, data of poor quality, land data suffering from topography and near-surface effects, or data with irregular acquisition geometries are expected to benefit from this approach.

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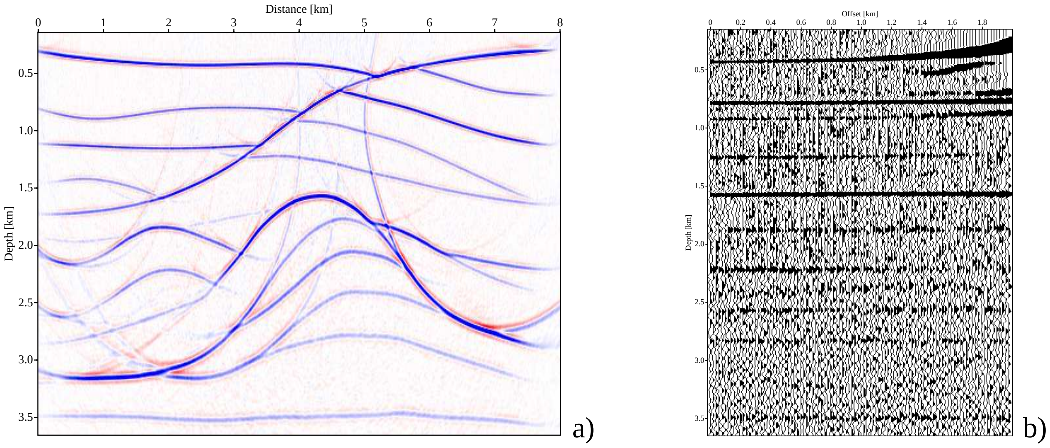

Figure 4: a) Prestack depth migration using the reconstructed smooth velocity model. All offsets up to 1000 m were stacked after the migration process. The migration artifacts are mainly caused by the missing diffraction events in the input dataset. b) Common-image gather at $x = 4200$ m from the prestack depth-migrated image using the reconstructed velocity model.

References

Bergler, S., Hubral, P., Marchetti, P., Cristini, A., and Cardone, G. (2002). 3D common-reflection-surface stack and kinematic wavefield attributes. *The Leading Edge*, 21(10):1010–1015.

Biloti, R., Santos, L. T., and Tygel, M. (2002). Multiparametric traveltime inversion. *Stud. geophys. geod.*, 46:177–192.

Duveneck, E. and Hubral, P. (2002). Tomographic velocity model inversion using kinematic wavefield attributes. In *Expanded Abstracts*, pages 862–865. Soc. Expl. Geophys.

Farmer, P., Gray, S., Hodgkiss, G., Pieprzak, A., Ratcliff, D., and Whitcombe, D. (1993). Structural Imaging: Toward a Sharper Subsurface View. *Oilfield Review*, 5(1):28–41.

Jäger, R., Mann, J., Höcht, G., and Hubral, P. (2001). Common-reflection-surface stack: Image and attributes. *Geophysics*, 66(1):97–109.

Majer, P. (2000). Inversion of seismic parameters: Determination of the 2-D iso-velocity layer model. Master's thesis, Universität Karlsruhe. http://www.wit-consortium.de/Downloads/diplthesis-pmajer.pdf.

Mann, J. (2002). *Extensions and applications of the Common-Reflection-Surface Stack method*. Logos Verlag, Berlin.

Müller, T. (1999). *The common reflection surface stack – seismic imaging without explicit knowledge of the velocity model*. Der Andere Verlag, Bad Iburg.

Schleicher, J., Hubral, P., Tygel, M., and Jaya, M. S. (1997). Minimum apertures and fresnel zones in migration and demigration. *Geophysics*, 62(01):183–194.

Sun, J. (2000). Limited aperture migration. *Geophysics*, 65(2):584–595.

Trappe, H., Gierse, G., and Pruessmann, J. (2001). Case studies show potential of Common Reflection Surface stack - structural resolution in the time domain beyond the conventional NMO/DMO stack. *First Break*, 19(11):625–633.

Vieth, K.-U. (2001). *Kinematic wavefield attributes in seismic imaging*. PhD thesis, Universität Karlsruhe. http://www.ubka.uni-karlsruhe.de/vvv/2001/physik/2/2.pdf.