Fresnel-Volume migration of elastic seismic data

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keywords: *Multicomponent migration, Fresnel volumes*

ABSTRACT

A method for imaging multi-component seismic data using vector Kirchhoff migration with a restriction to the Fresnel volume of the reflection wave path is proposed. This method is particularly applicable for seismic data with restricted aperture as, e.g. along tunnels or VSP. We use the polarization direction of multi-component data in order to construct the speculative reflection point of a recorded event. This enables us to restrict the imaging condition to the first Fresnel volume of the speculative reflected ray path. A test using synthetic seismic data simulating a VSP experiment shows that the method efficiently reduces migration artefacts and imaging of cross-talk phases. The method is applied to seismic data acquired in the frame of a pilot study at the Gotthard base tunnel construction site showing its ability to produce interpretable image volumes in spite of the restricted acquisition geometry.

INTRODUCTION

Seismic measurements are increasingly carried out with three-component (3C) receivers. Particularly for hydrocarbon exploration near salt, for VSP profiling, or for seismic exploration along tunnels, the complete wavefield is recorded in order to image reflected P-, S-, and converted waves (Ashida et al., 2002; Dickmann and Awasthi, 1999).

When imaging seismic data with a restricted spatial coverage of acquisition geometry it is desirable to restrict the migration operator to the region around the point of a speculative reflection in order to avoid migration artefacts. As long as sufficient spatial coverage is given, slowness-analysis of one-component recordings can be used to derive wave propagation direction at the receiver and thus construct the reflecting surface to which imaging is to be restricted (Tillmans, M. and Gebrande, 1999). Takahashi (1995) introduced a method to use the polarisation angle from multicomponent recordings to resolve the spatial ambiguity and weight the amplitude to be imaged using the angle between measured and expected polarization. Müller (2000) showed that this strategy was especially suited to image diffractions. The aim of this strategy is to restrict the migrated image of a reflection to the physically relevant part of the image volume, which is the Fresnel volume of a speculative ray (Sun, H. and Schuster, 2003).

CONCEPT OF FRESNEL VOLUME MIGRATION

Scalar Kirchhoff migration of a single seismic trace consists in a weighted smearing of the recorded amplitude along the line of constant two-way traveltime (isochrone), where the weighting is dependant on the recording geometry and velocity distribution. When elastic multi-component data are to be imaged, the amplitude to be smeared is the inner product of the multi-component data and the expected direction of polarization (Takahashi, 1995). Especially using data with limited spatial aperture, strong migration artefacts are produced due to the slow decay of the inner product with increasing angle between measured and expected direction of polarization. Goertz et al. (2003) proposed to use the definition of the Fresnel volume of a seismic ray to restrict the smearing of the amplitude to that part of the isochrone which physically contributes to the recorded reflection.

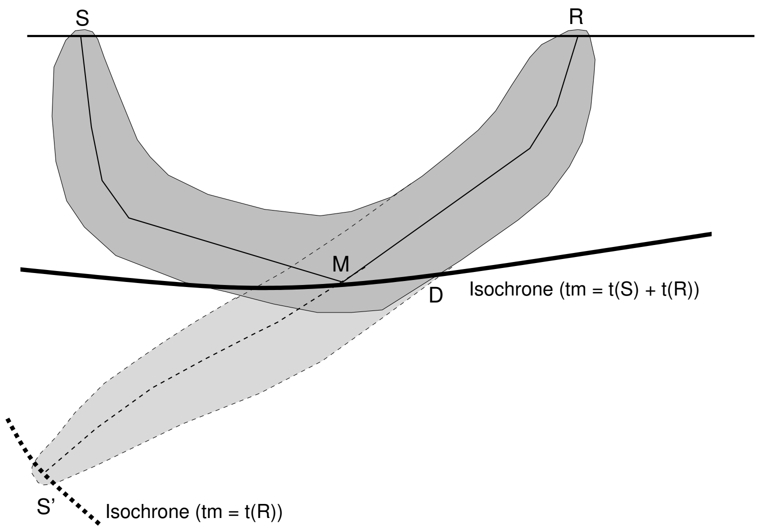

Figure 1: The Fresnel volumes of a reflected ray path SMR and a direct ray path S'R in a non homogeneous velocity field. Instead of constructing the Fresnel volume of ray SMR (dark shaded area), which requires two-point ray tracing, we trace the ray S'R backward from R to S'. The initial propagation direction of the ray is defined by the propagation direction of the seismic signal recorded at R.

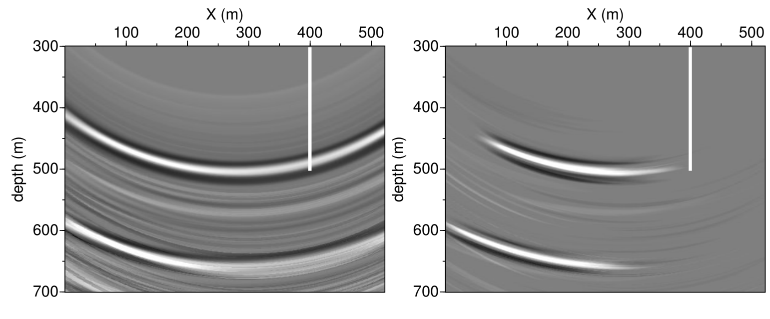

Figure 2: Migration results of a FD simulation of a VSP-experiment. One shot at the surface at X=150 m was recorded by 20 3C receivers at 25 m depth interval in a borehole (white line at X=400 m). Two dipping reflectors in a background medium with a downward positive velocity gradient are imaged. On the left, the result of vector-Kirchhoff migration is shown, on the right, the result of Fresnel volume migration. In the left image it is not possible to decide where the reflectors are actually located. On the right, amplitudes are restricted to the vicinity of the actual reflecting points.

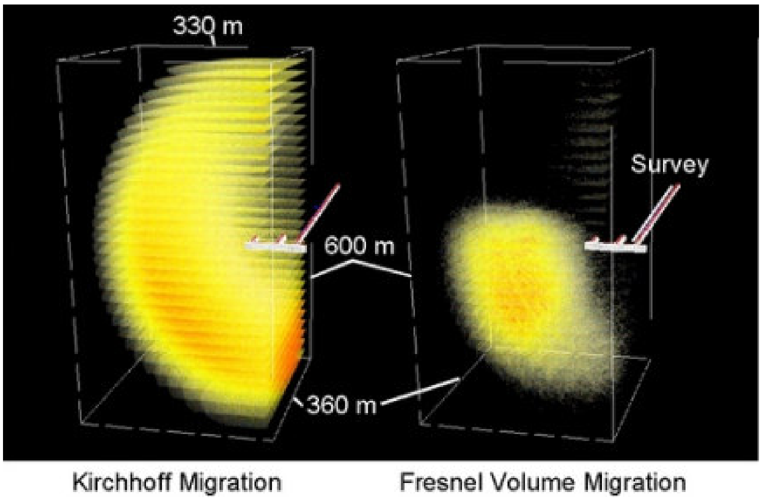

Figure 3: Migration results of ten receivers recording all 408 shots respectively of seismic pilot survey. The survey was carried out along the long tunnel, the image volume is bounded by a white box. Backscattered energy is focused much more efficiently by Fresnel Volume migration, compared to Kirchhoff migration.

MODIFICATION FOR HETEROGENEOUS VELOCITY FIELDS

The geometrical considerations described in Goertz et al. (2003) are not applicable in heterogeneous velocity fields due to the more complicated ray geometry. Consider the situation depicted in Fig. 1. The background velocity model is assumed to be laterally and vertically heterogeneous. The ray shot - reflecting point - receiver (SMR) has a rather complex shape, as well as its Fresnel volume. We construct one ray, starting at the receiver R with the direction of propagation derived by the polarization of the data. We compute the Fresnel volume of the ray using the paraxial approximation (Červený and Soares, 1992). The amplitude of the data is smeared only within the part of the isochrone which is within the Fresnel volume of the ray from R to S'.

A comparison of migration results from a FD simulated VSP experiment is shown in Fig. 2. Note the restriction of the two reflectors to small segments and the reduction of cross-talk phases in the Fresnel volume migration.

APPLICATION TO FIELD DATA

We apply the Fresnel-volume migration to data acquired within a pilot seismic experiment carried out at the location of the Gotthard base tunnel construction site in Switzerland (Borm et al., 2003). The survey consisted of 408 shots generated by a pneumatic hammer on the tunnel wall and 40 three-component receivers installed in boreholes along the tunnel wall. The images shown in Fig. 3 show the migration results of the first ten receivers which recorded all 408 shots, respectively. The Kirchhoff migrated image focuses backscattered energy at the same location as the Fresnel volume migration but migration artefacts remain particularly in the planes perpendicular to the survey line.

CONCLUSIONS

A method for imaging 3C seismic recordings with small spatial aperture in heterogeneous velocity fields is proposed. The vectorial recording is used to derive the direction of propagation at the receiver, which is the initial condition for a Fresnel-ray traced into the model. The amplitude to be imaged is restricted to the part of the isochrone which is within the ray's Fresnel volume. Compared to vector Kirchhoff migration the image of a reflector is restricted to the physically relevant part of the image volume and the imaging of cross-talk phases is considerably reduced.

ACKNOWLEDGEMENTS

This research has been funded by GeoForschungsZentrum Potsdam. We thank the GeoForschungs Zentrum Potsdam for providing the field data from the Gotthard base tunnel construction site. E. Saenger (FU Berlin) gave the FD Modeling code for generating synthetic test data.

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