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Seismic constant-velocity remigration

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ABSTRACT

When a seismic CMP stack or zero-offset (ZO) section is depth- or time-migrated with different (constant) migration velocities, different reflector images of the subsurface are obtained. If the migration velocity is changed continuously, the (kinematically) migrated image of a single point on the reflector, constructed for one particular seismic ZO reflection signal, moves along a circle at depth, which we call the Thales circle. It degenerates to a vertical line for a non-dipping event. For all other dips, the dislocation as a function of migration velocity depends on the reflector dip. In particular for reflectors with dips larger than 45°*, the reflection point moves upward for increasing velocity. The corresponding curves in a time-migrated section are parabolas. These formulas will provide the seismic interpreter with a better understanding of where a reflector image might move when the velocity model is changed. Moreover, in that case the reflector image as a whole behaves to some extent like an ensemble of body waves which we therefore call remigration image waves. In the same way as physical waves propagate as a function of time, these image waves propagate as a function of migration velocity. Different migrated images can thus be considered as snapshots of image waves at different instants of migration velocity. By some simple plane-wave considerations, image-wave equations can be derived that describe the propagation of image waves as a function of the migration velocity. The Thales circles and parabolas then turn out to be the characteristics or ray trajectories for these image-wave equations.*

INTRODUCTION

It is well known in seismic migration that an identified and picked reflection-time curve in a common-midpoint (CMP) stack or zero-offset (ZO) section leads to different (depth or time) migrated reflector images when different migration velocities are used. To transform these migrated reflector images from one to another in a direct way, i.e., without going back to the original CMP or ZO section, is a seismic imaging task that can be achieved by a residual or cascaded migration. In this way, an improved seismic reflector image for an improved migration velocity is obtained by applying a migration operator to

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the already migrated rather then unmigrated section. Residual migration is based on the fact that the migrated image obtained from migrating a second time (with the migration velocity v_2) a seismic section that has already been migrated (with the migration velocity v_1) is identical to the one that would have been obtained from migrating the original CMP or ZO section once, with the effective migration velocity $v_{eff} = \sqrt{v_1^2 + v_2^2}$ (Rocca and Salvador, 1982). Given the first ("wrong") migration velocity v_1 and the desired effective ("true") migration velocity v_{eff}, a residual migration is nothing more than a conventional migration with the residual migration velocity $v_2 = \sqrt{v_{eff}^2 - v_1^2}$ (Rothman et al., 1985). Cascaded migration involves an iterative procedure (Larner and Beasley, 1987). By performing n times a migration with a small velocity increment Δv, the desired effective migration velocity $v_{eff} = \sqrt{n \Delta v^2}$ is finally reached. Is is not difficult to accept that by choosing a large number n of steps and a very small velocity increment Δv, a cascaded migration simulates a quasi-continuous change of the migration velocity. In this paper, we investigate how the image of a selected target reflector or a complete post-stack (depth- or time-) migrated seismic section changes when the (constant) migration velocity is continuously changed. This process of continuously changing the migration velocity until a certain desired (optimum) value is reached is termed a seismic remigration.

Note that this paper will not deal with other causes for wrongly migrated reflector images apart from those resulting from an incorrect (constant) migration velocity. The question of how to correct for migration errors that occur due to the use of time migration for media that require depth migration (Black and Brzostowski, 1994) is discussed in Bevc et al. (1995). Also, this paper does not deal with the question of how the migrated reflection point moves locally when an inhomogeneous background macro-velocity model is perturbed. For this problem we refer to Iversen (1995). Here, we confine ourselves to a (continuously changing) constant migration velocity.

This paper is structured as follows. In the first section, we give a kinematic explanation of what we call "image waves." In the second section, we derive their kinematic features and the corresponding partial differential equations for depth remigration. Finally, in the third section we give the parallel derivations for the time remigration. Note that the present derivations of these differential equations differ from those of Hubral et al. (1996b) who start from "Huygens image waves" and of Fomel (1994) who does not discuss depth migration at all.

CONCLUSION

Remigration is a process to construct a seismic depth image for a refined velocity model from another one already available from a previous migration for a different velocity model. A solution to the general problem has been recently presented (Hubral et al., 1996a; Tygel et al., 1996). In this paper, we have tried to provide a more geometric understanding of the process by restricting ourselves to the simple case of a constant migration velocity.

When a seismic CMP stack or zero-offset (ZO) section is depth- or time-migrated with different (constant) migration velocities, different reflector images of the subsurface are obtained. Here, we have investigated how the migrated image of a single (kinematic) reflector changes when the migration velocity is changed continuously. We have observed that the reflection point constructed for one particular seismic ZO reflection signal moves along a circle at depth, which we have referred to as the Thales circle. It degenerates into a vertical line for a non-dipping event. For all other dips, the dislocation as a function of migration velocity depends on the reflector dip. In particular for reflectors dipping above $45°$, the reflection point moves *upward* for *increasing velocity*. The corresponding curves in a time-migrated section are parabolas. These formulas will provide the seismic interpreter with a better understanding of where a reflector image might move when the velocity model is changed.

Moreover, we have recognized that, under these conditions, the reflector image as a whole behaves to some extent like an ensemble of “body waves” which we therefore called image waves. In the same way as physical waves propagate as a function of time, we can say that remigration image waves propagate as a function of migration velocity. Different migrated images can thus be considered as snapshots of image waves at different instants of migration velocity. By some simple plane-wave considerations, we have set up image-wave equations that describe the propagation of image waves as a function of the migration velocity. The Thales circles and parabolas then turn out to be the characteristics or ray trajectories for these image-wave equations.

How to generalize the concept of image waves to inhomogeneous media remains an unsolved problem. At first sight, the restriction to constant velocity seems intrinsic to the concept. However, at least in media consisting of constant-velocity layers, an application of the remigration image-wave equations seems possible using a layer-stripping approach. Moreover and most intriguingly, even a reflector image below an inhomogeneous overburden formally behaves like a wavefront if the overburden is continuously changed, even though we presently do not know how to construct an appropriate image-wave equation that describes this propagation.

As this paper is mainly devoted to the intuitive understanding of seismic remigration, we have refrained from providing synthetic examples. Note, however, that first applications of a finite-difference version of the time-remigration image-wave equation to synthetic data indicate that the method is a powerful tool that can even compete with such renowned constant-velocity migrations as that of Stolt (1978) as soon as reflector images for more than one migration velocities are required (Jaya et al., 1996).

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PUBLICATIONS

Detailed results were published in Geophysics (Schleicher et al., 1997).