Wave Inversion Technology, Report No. 1, pages 55-60

A new look at subsurface illumination in seismic imaging

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keywords: *Imaging Stacking*

ABSTRACT

To improve the illumination of the subsurface is the purpose of every seismic acquisition and imaging method. The success of standard seismic/stack imaging routines, such as Kirchhoff-type Pre-stack Depth Migration or NMO/DMO/stack depends on the required macro-velocity model. From kinematic point of view they also implicitly assume with respect to the illumination a fixed shape of the reflector. In contrast a common-reflection surface stack is a selective stack depending only on the near-surface velocity. It accounts for different reflector shapes and enables us to establish the macro velocity model after the zero-offset simulation.

INTRODUCTION

In this paper we give an insight into different stacking routines from a kinematic point of view. As representative for standard imaging methods we have chosen the NMO/DMO/stack and the pre-stack depth migration (PreSDM). The latter two processes are for comparison implemented in the form of unweighted Kirchhoff-type (target-oriented) procedures. With the objective to improve images and the macro-model determination we introduce the so-called common-reflection-surface (CRS) stack, which is closely related to “multi-focusing” proposed by (Berkovitch et al., 1994). The CRS stack provides in our opinion a new powerful approach to construct simulated zero-offset (ZO) sections from multicoverage reflection data. In addition to the simulated ZO section we obtain important wavefield attributes that enable us to construct the macro-velocity model ((Hubral, 1983), (de Bazelaire and Viallix, 1994)).

MACRO-VELOCITY-MODEL BASED IMAGING

To explain in simple terms the ”standard illumination” of a subsurface reflector point R involved in all standard reflection imaging methods, we have constructed Fig. 1. This

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shows a dome-like subsurface reflector in the lower constant-velocity half space and traveltime curves from the reflector in the midpoint(x)-half-offset(h) and time(t) domain. All common-offset (CO) reflection-time curves define the so-called CO-reflection-time surface of the subsurface reflector in the (x-h-t) space. The reflections from the subsurface reflector point R are found in the (x-h-t) space along the so-called common-reflection-point (CRP) trajectory, which is confined to the CO-reflection-time surface.There exists a simple analytic formula in the constant-velocity case for the CRP trajectory.

NMO/DMO/Stack

In NMO/DMO/stack the reflections from point R along the CRP trajectory are transported into point P_0 by summing the seismic data in the (x-h-t) space along the Kirchhoff-type MZO-stacking surface. This corresponds to the following traveltime surface: First, construct the zero-offset (ZO) depth-migrated image of point P_0, which is the lower half-circle isochrone of P_0 centered at X_0 in Fig. 1. Then demigrate this isochrone back into the (x-h-t) domain for the respective offset 2h.

PreSDM

In pre-stack depth migration the reflections from point R distributed along the CRP trajectory (bold curve in the (x-h-t) space in Fig. 1 and 2) are transported into point R. This is achieved by summing all seismic data in the (x-h-t) space along the Kirchhoff-type CO migration pre-stack surface. This surface corresponds to the traveltime surface in the (x-h-t) space constructed for a ”diffractor point” at R.

CRS Stacking

In Fig. 2, we have placed into point R an arc pertaining to the reflector circle C_R. This arc becomes in 3D a surface, which justifies the terminology CRS. The arc is assumed to have the same orientation and radius of curvature as the searched-for reflector at R. The trajectories define a travel-time surface in (x-h-t) space, which we call the CRS surface for point$R$. Our purpose is to find this surface and then use it as a stacking surface for point P_0. This is implemented in the following way.

Select an arbitrary point P_0 in the (x-t) plane, for which one wants to find the amplitude value of the CRS stack. Affix at the resulting ZO isochrone in the depth domain different circular reflector arcs (”test mirrors”) and perform for each of them a coherency analysis along the corresponding CRS surface in the time domain. For the CRS surfaces of those test mirrors, which lead to large coherency values, we subsequently perform the CRS stack. These surfaces will obviously pertain to actual reflector mirrors that locally approximate the searched-for reflectors. As search parameters we use, at X_0, the incidence angle α and the radius of a hypothetical wavefront R_N that results if the cho-

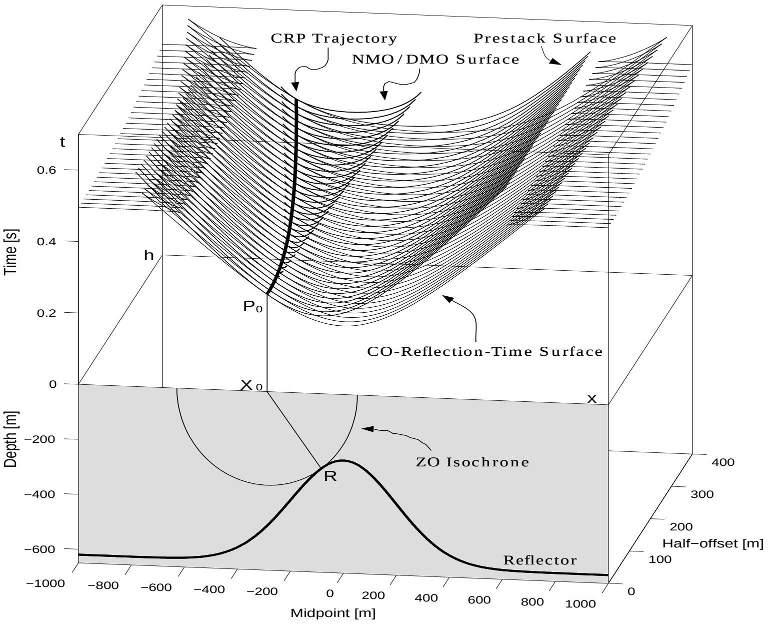

Figure 1:
Lower Half: Dome-like structure touched at point R by the ZO isochrone (half-circle with center at X_0) of P_0.
Upper half: CO-reflection-time surface in (x-h-t) space, to which the CRP trajectory of point R is confined. Shown are also the NMO/DMO-stacking surface and the pre-stack-depth-migration surface. Both are tangent to the CO-reflection-time surface along the CRP trajectory.

sen circular mirror explodes. The intention of the latter procedure will become clear in laterally inhomogeneous media.

NMO/DMO/stack and PSDM versus CRS stacking

We observe that the NMO/DMO/stack always assumes a curvature of the reflector equal to that of the ZO isochrone. Likewise PreSDM decomposes the reflector into ”diffraction points”, i.e. a radius of curvature that equals zero. Only CRS stacking can obviously account for the right shape of the reflector since the radius of curvature is one of the search parameters. Note that the CRS stacking surface can be spatially limited over the range (aperture) where the reflections are, so that a minimum amount of noise is added when we consider noisy data. Such a spatial limitation is not easy to achieve a priori for the CO stacking curves required for the NMO/DMO/stack or PreSDM. Therefore NMO/DMO and PSDM does not provide the best reflector illumination but has the advantage that one does not have to consider a coherency analysis and event selection. However to consider the search can be quite rewarding.

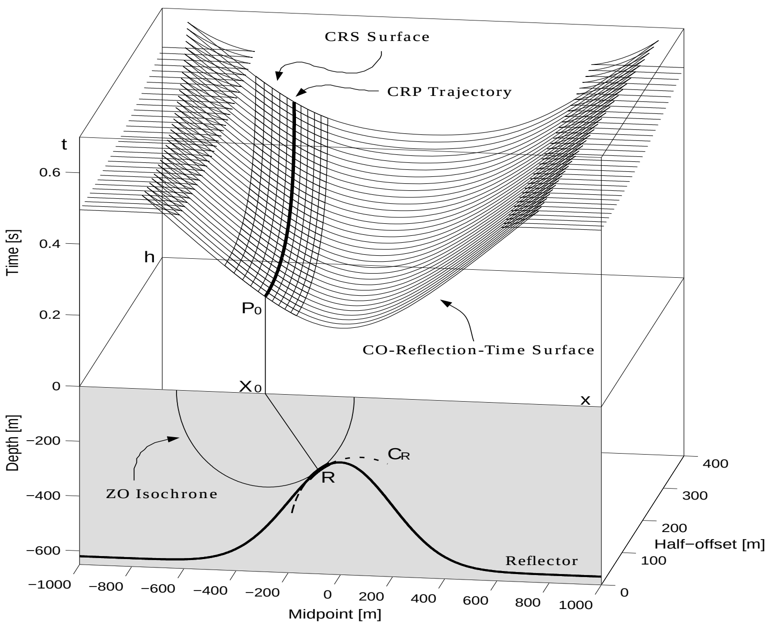

Figure 2:
Lower Half: As in Fig. 1. Dashed is a segment C_R of a circle that possesses the same curvature as the reflector at R.
Upper half: CO-reflection-time surface from dome-like reflector and the common-reflection-arc surface gained by circular approximation of the reflector at R.

IMAGING WITHOUT MACRO-VELOCITY

The above proposed CRS stack can be generalized for laterally inhomogeneous macro-velocity models, which would involve substantial ray tracing. Our purpose is to establish the CRS surface with only the knowledge of the constant near-surface velocity v_0, using a very good analytic approximation of the non-analytic CRS stacking surface in inhomogeneous media.

In order to achieve the goal we replace the a priori unknown true 2D velocity model by an auxiliary constant-velocity model v_0, where v_0 is the constant near-surface velocity of the true velocity model. In addition to a CRS stack in constant velocity media we introduce a third search parameter which we call R_{NIP}. It equals the radius of curvature of a hypothetical wavefront emerging at X_0 in the auxiliary media, resulting from a point source in the chosen point where the test mirror is affixed to the ZO isochrone. The resulting three parameters α, R_N and R_{NIP}, pertain to the emerging normal ray at X_0 in the true as well as in the auxiliary velocity model. They can consequently be found with the help of a three-parameter coherency analysis. No ray tracing is involved in finding the CRS surface of the reflector mirror, even though the true 2D velocity model away from the constant velocity near the surface may be quite complicated.These attributes - and there can be more than one set assigned to a point P_0 - are useful not only with respect to solving kinematic (related to finding the macro-velocity-model) but also dynamic (related to the amplitudes, Fresnel zones, etc. of the wavefield) inversion problems.

CONCLUSION

In the view of the authors, CRS stacking offers exciting new approaches to solve seismic reflection imaging and inversion problems in 2D and 3D laterally inhomogeneous media. It is important to stress that macro-model independent CRS stacking in laterally inhomogeneous media is implemented without any raytracing. The attributes obtained in connection with macro-model independent CRS stack are useful to derive the macro-velocity model. Thereafter one can perform a PostSDM of the stack section. Both the stack section and its attributes are in their combination very helpful to address moreover a number of seismic reflection-imaging and inversion problems related to reflector characterization, high-resolution studies, noise suppression, multiple identification suppression, separation of diffraction from reflection events, etc.

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PUBLICATIONS

Detailed results were published by (Höcht et al., 1996).