E015 DEPTH CONSISTENT PP AND PS SEISMIC ANGLE TOMOGRAPHY

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Abstract

PP and PS depth migration should map key geological horizons to the same depths. These depths should also coincide with the depth points estimated from well logs, if such are available. The depth migrated images depend on the elastic parameters defining a background model. These are estimated by minimizing a differential semblance function which requires amplitude-corrected angle-domain common-image gathers to be uniform. That is, the migrated events have the same amplitude and depth for each angle. The velocity-depth ambiguity contributes to the non-uniqueness of the problem. This means that uniform gathers is not a sufficient criteria for depth consistency between PP and PS migrated images. The mistie of pairs of key reflectors in the PP and PS image is added as a penalization term in the velocity estimation. By using map migration of time information of the two reflections the depth mistie can be quantified in an automatic way given a background medium.

We suggest a strategy for building a transversely isotropic (TI) background model by using the time information of the PP and PS time horizons in junction with the redundancy of common image-point gathers used in classical migration velocity analysis. Starting from simple isotropic assumptions, the information using the aforementioned tools is used to attain values for all parameters of a TI representation. Well log information must be included to further constrain the solution. An example is given using ocean bottom seismic data from the North Sea.

Introduction

The differential semblance (Symes and Carazzone, 1991) misfit function in angle, for the purpose of tomography, was formulated and applied to a synthetic PP data example by Brandsberg-Dahl *et al.* (2003). An optimal solution is obtained for uniform common image-point gathers (cigs). The gathers are created by AVA-compensated migration (Ursin, 2003). However, the velocity-depth ambiguity in depth migration, stemming from several factors such as, limited aperture, band-limited source and the interplay between parameters of the background medium (Bube and Meadows, 1999), contributes to the non-uniqueness of the reflector depths even for uniform cigs. The isotropic assumption can also cause severe depth errors in the presence of anisotropy.

Here, the differential semblance function is adapted to PS reflections and the depth inconsistency of the PP and PS image is quantified as function of the background model. This results in a strategy (Sollid and Ettrich, 1999) for estimating the parameters of a TI media with a known symmetry axis. Results are illustrated by a North Sea ocean bottom seismic data set.

PP and PS angle tomography and co-depthing

Each parameter of the background medium is given some finite dimensional representation described by certain coefficients m_i, where the collection of all such coefficients are given by $\mathbf{m}=\{ m_i \}$. A PP common image-point gather computed with a particular background model **m** at an imaging point $\mathbf{y}=(y_1,y_2,y_3)$ for a scattering angle θ and azimuth ψ, is denoted $I_{PP}(\theta,\psi;\mathbf{y},\mathbf{m})$. The differential semblance misfit function for PP scattering is found in Brandsberg-Dahl et al. (2003). Due to the diodic nature of the PS reflections we split the contributing events of the cigs in the misfit function into a 'positive' and 'negative' constituent, denoted by I_{PS}^+ and I_{PS}^-. The I_{PS}^+-cigs are computed with seismic events where the source and receiver rays intersect at the imaging point in the order of Figure 1 relative to the scattering angle and in opposite order for I_{PS}^-. This splitting is necessary in the tomographic procedure as the rays, for the two cases, travel in different parts of the background model. This is contrary to the PP reflection events which are symmetric in the sense that substituting the receiver and source location yield rays that have traveled along the same paths in the medium, but in reverse order. The complete PS misfit function is given by

(1) $$J(\mathbf{m})=1/2\iiint [|\partial_{\theta,\psi}I_{PS}^+(\theta,\psi;\mathbf{y},\mathbf{m})|^2 + |\partial_{\theta,\psi}I_{PS}^-(\theta,\psi;\mathbf{y},\mathbf{m})|^2]\, d\theta d\psi d\mathbf{y}.$$

Given the cigs the differential semblance misfit functional can be calculated and an optimal solution found by a gradient-based method.

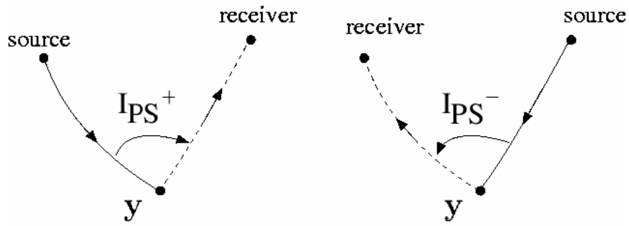

Figure 1. Arrows indicate the wavefield propagation directions in the two reflection events. The solid and dashed curves are the P- and S-wave legs, respectively.

The misfit function, for co-depthing the PP and PS images, considers chosen pairs of key reflectors which should be easily recognized and paired as the physically equivalent reflectors in both images. The misfit function penalizes mistie between chosen key reflectors in both PP and PS images. Map migration enables direct comparison in depth for every background model. By using time information of the reflectors, which is independent of any background model, the reflectors need only be picked once. Allowing for mild lateral inhomogeneity and transversely isotropic media, we employ traveltimes obtained by demigration of the normal incidence point (NIP) rays from traced key reflectors on initial depth images or for simple situation a stack section can be used. The traveltimes are now 'data'. These enable the reverse map to depth given a background model for pure mode events. The PP traveltime maps are obtained directly from PP data, and an approximate estimate of the SS traveltime map is obtained from PS and PP data. The latter uses a NIP ray approximation of Grechka and Tsvankin's (2002) 'PP+PS=SS'-concept, removing the P-leg of the PS event using the PP traveltimes. This decouples the estimation of the P- and S-wave vertical velocities.

Strategy for depth consistent PP and PS tomography in a TI media

Using the aforementioned tomography tools we obtain values of a TI medium with a known symmetry axis. The method is illustrated with an ocean bottom seismic data set from the North Sea. The medium is equivalent to a TI medium with a vertical symmetry axis through the Bond transformation. It can be parameterized by the four parameters v_{P0}, v_{S0}, ε and δ which are the vertical P- and S-wave velocities and the Thomsen (1986) parameters, respectively. The optimization strategy is performed in a step-wise manner to improve stability and ability for quality control. It is split into the following steps:

1. Isotropic P-wave velocity analysis on PP common image-point gathers. The resulting image in Figure 2 was found by Foss et al. (2003). This P-wave velocity is fixed in the next two steps.

2. Isotropic S-wave velocity analysis on PS common image-point gathers using the P-wave velocity from step 1. The resulting image is given in Figure 3. This image and the PP image in Figure 2, yield time information of reflectors through demigration to be used in the co-depthing procedure described above. Indicated are three reflectors a), b) and c) used in this step. The c) reflector of the PP image is traced and superimposed on the PS image. Observe that it seems to match some reflector in depth, but the physically equivalent reflector is indicated with a dotted line at a much larger depth in the image.

3. Depth consistency between PP and PS images through optimization on S-wave velocity by map migration.

4. Uniform gathers through optimization of the anisotropic parameters keeping the depth consistency. The depth consistency is in large part governed by the δ-parameter. The current P-wave velocity is close to an NMO velocity v_{NMO}, while the S-wave velocity is after co-depthing is the vertical S-wave velocity v_{SO}. The depth consistency is ensured by keeping the vertical P- and S-wave ratio fixed. This is done by updating the velocities for every suggested δ-value in the optimization, $v_{P0} = \frac{v_{NMO}}{\sqrt{1+2\delta}}$ and $v'_{S0} = \frac{v_{S0}}{\sqrt{1+2\delta}}$, where v'_{S0} is the updated vertical S-wave velocity. Several authors have discussed that in order to estimate the δ-parameter you either need information on the true depth of a reflector through well logs or time information from rays that have traveled at an oblique angle e.g. from strongly dipping reflectors or from large offset data (Audebert *et al.*, 2000). In the absence of such information several approachs have been suggested (Alkhalifah and Tsvankin, 1995; Grechka and Tsvankin, 2002) e.g. by simply setting the δ-parameter to zero and optimizing for an effective anisotropic parameter through the epsilon-parameter. In the present example there were no well log information and a tight mute on the early parts of the data. We chose to set δ=0 in the shallow part above 1500 meters until sufficient large offset data could be used. The resulting co-depthed PS and PP image after anisotropic update are given in figures 4 and 5, respectively. The indicated interfaces a), b) and c) shows reasonable depth consistency. Due to 3-D effects in the data below reflector c) it was not possible to focus the PS image (Figure 4) in this region.

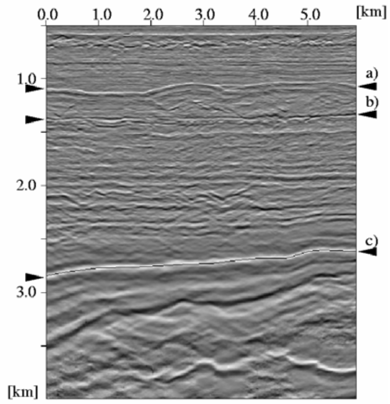

Figure 2. PP image from isotropic update.

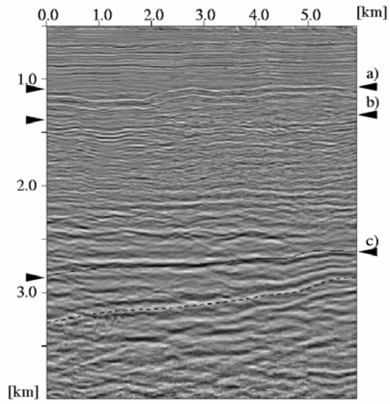

Figure 3. PS image from isotropic update.

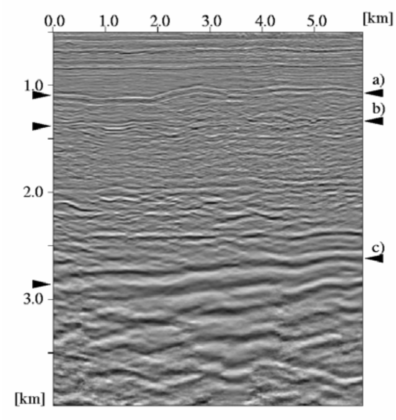

Figure 4. PS image after co-depthing and anisotropic update.

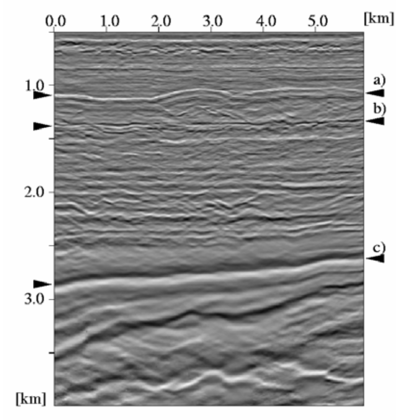

Figure 5. PP image after anisotropic update.

Conclusion

The method shows promising ability to achieve depth consistency and uniform gathers at the same time. The method relies on the ability to identify and pair equivalent interfaces of the PP and PS image.

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