Dip-correction for coherence-based migration velocity analysis

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Abstract

Migration velocity analysis (MVA) is a seismic processing step that aims at translating the velocity information that is contained in the residual moveout in an image gather after migration with an erroneous velocity model into velocity updates. In this paper, we extend the original coherence-based MVA approach to dipping reflectors. We devise a new MVA technique, where the reflector dip is treated as an additional search parameter that is to be detected together with the velocity updating factor. A numerical example demonstrates that the additional search parameter can indeed be helpful to improve the quality of the velocity updates.

Introduction

Migration velocity analysis (MVA) is a seismic processing step that exploits the redundancy of seismic data to improve an a-priori velocity model. The basic idea is to use the velocity information that is contained in the residual moveout in an image gather, translating this residual moveout into velocity updates. Of course, the process can be applied repetitiously, thus generating a loop between migration, MVA, and velocity updates, which is terminated when the residual moveout is sufficiently flattened.

In this paper, we follow the lines of the coherence-based approach of Al-Yahya (1989). In other words, we propose a semblance analysis along certain stacking curves within the data. This approach has the advantage that no picking is needed. We extend the method of Al-Yahya (1989), which was restricted to horizontal reflectors, to dipping reflectors. A first attempt in this respect was undertaken by Lee and Zhang (1992) using near-offset and small-dip approximations. Here, we keep the assumption of small dips ($< 45°$) but drop the restriction to small offsets.

We devise a new MVA technique, where the reflector dip is treated as an additional search parameter which is to be detected together with the velocity updating factor. Both parameters are searched-for simultaneously by the application of techniques that have been developed in connection with the common-reflection-surface (CRS) stack (Biloti et al., 2002). Like for that method, the search is carried out by determining trial curves as a function of the search parameters and stacking the migrated data along these curves. The highest coherence determines the
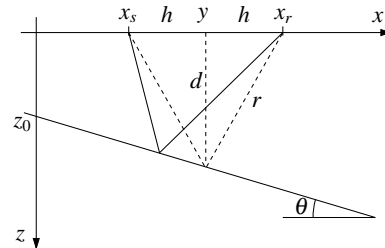

Figure 1: Reflector and acquisition geometry.

best-fitting curve and thus the optimal, i.e., best-possible, parameter pair.

Dipping reflector image

As a basis for the stacking technique, we need a theoretical expression for the position of a migrated reflector image as a function of the (wrong) migration velocity. For this purpose, we consider a dipping reflector with dip $m = \tan\theta$, where θ is the dip angle. The depth z of this reflector at a horizontal position x is thus described by the formula $z = mx + z_0$, where z_0 is the depth of the reflector vertically below the coordinate origin (see Figure 1). We consider the reflector to be buried in a homogeneous medium with true velocity v.

Next, we consider a 2D seismic experiment being carried out over this medium along the x-axis. Sources and receivers are positioned at points $x_s = y - h$ and $x_r = y + h$, where y and h are the (varying) midpoint and half-offset coordinates (see again Figure 1). Then, the traveltime surface of the reflector in the data cube will be given by an expression of the form

$$t_{\text{ref}} = \frac{1}{v}\left(\sqrt{(x-y+h)^2 + (mx+z_0)^2} + \sqrt{(x-y-h)^2 + (mx+z_0)^2}\right), \quad (1)$$

where x denotes the horizontal coordinate of the reflection point. By applying Fermat's principle, it can be shown that the actual traveltime is, as a function of y and h,

$$t_{\text{ref}} = \frac{2}{v}\sqrt{\frac{h^2 + (my+z_0)^2}{1+m^2}} \ . \quad (2)$$

The reflection event located at the traveltime (2) in the data is now to be migrated using the (wrong) migration velocity v_m. Its position in a common-offset time-migrated section can be constructed as the envelope of the common-offset isochrons for all points (y, t_{ref}) in the data. Any of these

isochrons is described by the lower half-ellipse

$$t(x;y,h) = \frac{2b}{v_m} \sqrt{1 - \frac{(x-y)^2}{a^2}} \, , \qquad (3)$$

where t is the vertical time $t = 2z/v_m$ and where the semi-axes are given by $a = v_m t_{\text{ref}}/2$ and $b = \sqrt{a^2 - h^2}$. Here, x describes the horizontal coordinate of the image to be constructed. Since we are interested in the position of the image in an image gather, i.e., for a constant x, we can assume without loss of generality that the coordinate origin is located at the position of the present image gather, i.e., $x = 0$. Then, z_0 has the meaning of the true depth of the reflector at the considered image point.

Upon substitution of formula (2) for t_{ref} in equation (3), we obtain the family of isochrons. The reflector image is given by the envelope of the family of isochrons. Unfortunately, the computations can not be carried out explicitly for y. We therefore have to look for an approximate envelope. For this purpose, we use the Taylor series up to third order in m. After some tedious algebraic manipulations, the final expression for the position of the reflector image in the image gather reads thus

$$t_{\text{ig}}(h) \approx \tau + (1 - \gamma^2) \frac{(4\gamma^2 h^2 + v_m^2 t_0^2)(4h^2 - v_m^2 t_0^2)}{2v_m^4 \tau^3} \, m^2 \, , \qquad (4)$$

where

$$\tau = \sqrt{t_0^2 + (\gamma^2 - 1)4h^2/v_m^2} \, , \qquad (5)$$

and $\gamma = v_m/v$ is the ratio between the migration and true medium velocities as defined by Al-Yahya (1989).

We immediately observe that equation (5) is exactly Al-Yahya's expression for the image position of a horizontal reflector. Note that the additional factor 4 in the last term under the square root is due to the fact that Al-Yahya (1989) considers a migration slowness that corresponds to twice the medium slowness, i.e., his w_m relates to v_m as $w_m = 2/v_m$. Since Al-Yahya's expression is the first term of formula (4), we can interpret its second term as a dip-correction to Al-Yahya's formula. We stress that equation (4) is a third-order approximation in m. In other words, the first and third-order terms in m are zero. Therefore, the image gather contains no information about the sign of m, i.e., of the direction of the dip.

Search technique

As suggested by Al-Yahya (1989) for its first term, we use equation (4) to carry out coherence analysis along trial lines defined by this equation. However, instead of searching for a single parameter γ for each t_0, we search for two of them, being γ and m. While γ, as before, is meant to determine an estimate for the true medium velocity from the migration velocity as $v_{\text{est}} = v_m/\gamma$, the main role of the second parameter m is to stabilize the search and get better estimates for γ in situations with dipping interfaces and/or where the first guess for v_m was quite bad. The actual values of m can be useful at the interpretation stage.

To determine the optimal values for γ and m, a biparametrical search has to be carried out, which requires starting values for both parameters as close as possible to their optimal values. To determine these starting values, we first search one-dimensionally for each of them independently with the following strategy.

Since our dip-correction was derived from a Taylor expansion for small m, the first stage of the search is to look for a value of γ that maximizes the coherence measure with m set to zero. In other words, the starting value for γ is obtained by a search using Al-Yahya's formula only. Once an initial estimate for γ has been found, a second one-dimensional search is performed with fixed γ to obtain an approximation for m. Finally, a derivative-free optimization method is employed to obtain the best possible values for γ and m simultaneously. This strategy follows the same search technique successfully employed to simultaneously obtain the three traveltime attributes of the Common-Reflection-Surface (CRS) stack (Birgin et al., 1999).

Numerical example

In this section, we demonstrate the application of the dip-corrected migration velocity analysis to a synthetic data set. The depth model is depicted in Figure 2. It consists of two half-spaces separated by a single reflector, which has horizontal segments at the left and right sides of the model connected by a dipping reflector segment with a dip angle of 15 degrees. The wave speed is 2 km/s above the reflector and 3 km/s below it.
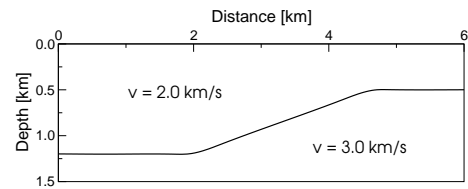

Figure 2: Model for the synthetic experiment. The two horizontal parts of the reflector are smoothly connected by a dipping reflector segment with a dip angle of 15 degrees.

Synthetic seismic data have been generated by an implementation of modeling by demigration (Santos et al., 2000). For the numerical experiment, 281 sources where simulated at every 25 m along the seismic profile between coordinates $x = -1000$ m and $x = 6000$ m with 241 source-receiver offsets at every 25 m from 0 m up to 6000 m. These data have been migrated with the incorrect migration velocity of 3.5 km/s. On the resulting image gathers, coherence-based migration velocity analysis has been applied using Al-Yahya's original traveltime formula (5) and our dip corrected one, equation (4).

The values of γ extracted from the sections along maximum coherence curves are compared in Figure 3. The values of γ obtained with Al-Yahya's formula (5) (red circles) quite accurately recover the true value of 1.75 at the horizontal parts of the reflector, but show a significant reduction at the dipping part. The values obtained with the dip-corrected formula (4) (green crosses) does a better job in this part, although suffering from more fluctuations. The dip-corrected formula (4) provides, as an additional parameter, the dip.

After updating the original velocity field with the gamma values of Figure 3 (at left), the resulting velocity have been smoothed with an optimal spline. As can already be seen in Figure 3 (at right), the dip correction has indeed succeeded in providing a better updated velocity field in the area of the dipping reflector.
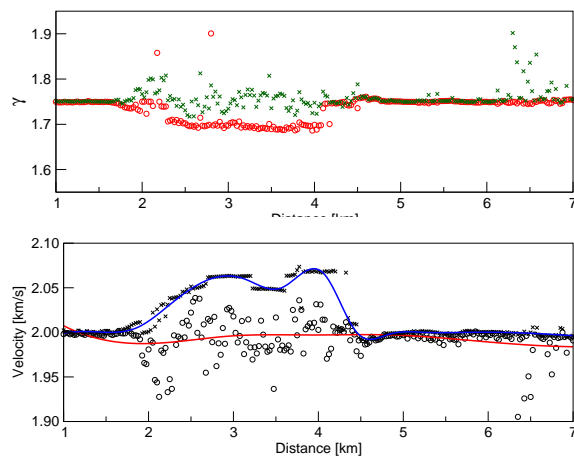
Figure 3: On top, values of γ as picked along the maximum coherence curves (Al-Yahya: red circles, dip-corrected: green crosses). On bottom, updated migration velocity as obtained from MVA using the Al-Yahya's formula (5) (point-to-point values: red circles, smoothed values: red solid line), and the the dip-corrected formula (4) (point-to-point values: red circles, smoothed values: blue solid line).

As a final test, the original data have been migrated with the updated velocity fields. The results are compared in Figure 4. While both methods image the horizontal parts of the reflector reasonably well, the dipping part is acceptably imaged only with the dip-corrected velocity.

Conclusions

In this paper, we have presented a dip correction to the coherence-based approach to migration velocity analysis (MVA) of Al-Yahya (1989). We have generalized the method of Al-Yahya (1989), which was restricted to horizontal reflectors, to dipping reflectors. In our new MVA technique, the reflector dip is treated as an additional search parameter, which is to be detected together with the velocity updating factor γ. Both parameters are searched-for simultaneously by the application of techniques that have been developed in connection with the common-reflection-surface (CRS) stack. A numerical example has demonstrated that the additional search parameter improves the estimates of the velocity ratio.

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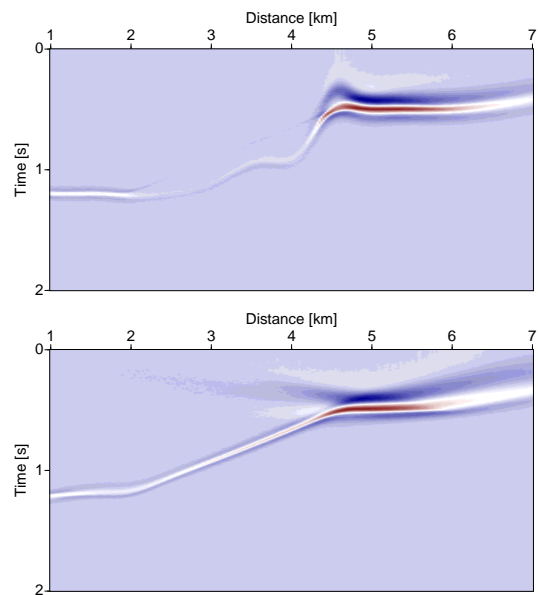Santos, L., Schleicher, J., Tygel, M., and Hubral, P., 2000,

Figure 4: Stack of migrated images using Al-Yahya's velocity update (top), and using the dip-corrected velocity update (bottom).

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