A new way to derive dense, robust and meaningful velocities for Imaging

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Introduction

Whether it is in Time or Depth domain, derivation of seismic velocities is a key step in the overall Imaging process. Long offsets and more demanding requirements regarding pre-stack data have forced us to give up isotropic propagation assumptions and to account for the anisotropy of the media. Time imaging is drastically improved when dense velocity *(V)* fields are used. However, this is not enough to focus the large offsets, to migrate the steep dips and finally to take into account the anisotropy of the sediments. The estimation of an extra dense parameter field is required: the effective anellipticity η. But the estimation of dense V and η fields using two-pass techniques has already reached its own limits. The estimation of both parameters is very sensitive to the mute function separating near to far offsets. V is closer to a stacking velocity than to the RMS velocity, and η is too far from the effective anellipticity defined by Alkhalifah (1997). Here we propose an original automatic dense bispectral picking using "orthogonal" parameters. Thanks to parameter decomposition, simultaneous interpolation and filtering of the dense V and η fields can be performed. Indeed with this "orthogonality" the effects of anisotropy are effectively separated from the velocity estimation and the resulting fields make more geological sense (RMS velocity - effective anellipticity). Furthermore, the gathers are almost perfectly flat which makes AVO analysis possible at any offset.

Today, the moveout equations are revisited and extended to non-hyperbolic shapes, which are generally parameterized using the anellipticity parameter η. This effective parameter encompasses the effects caused by ray bending through an isotropic-layered medium as well as by propagation in an anisotropic-homogeneous medium. Siliqi and Bousquié (2000) showed that the behavior of the vertical inhomogeneous media containing anisotropic layers remains of the ray bending type, but the magnitude of the far offset effects is mainly due to anisotropy and proposed the following anelliptic shifted hyperbola moveout equation:

$$t(V,\eta) = \frac{8\eta}{1+8\eta}\, t_0 + \sqrt{\left(\frac{t_0}{1+8\eta}\right)^2 + \frac{x^2}{(1+8\eta)V_2}}$$

x is the offset and t_0 the zero-offset traveltime (e.1)

In fact, customizing the moveout equation of the layered medium by introducing the anisotropy seems to be more accurate than customizing the moveout equation of homogeneous VTI medium by adding layers as proposed by Alkhalifah and Tsvankin (1995).

Velocity analysis requires the estimation of moveout corrections for several values of such test parameters. In the case where the test parameter is cleverly customized and the moveout corrections do not depend on t_0, automatic dense pickings are viable. The moveout corrections are indeed transformed into static shifts. Using parabolic approximations of residual moveout restricted to the hyperbolic part, Adler and Brandwood (1999) proposed an efficient automatic picking of velocity. Le Meur et al (2001) extended the method to the residual moveout due to the non-hyperbolic effect of η. By applying both methods in a cascaded way, it is possible to estimate two dense fields of effective parameters V and η. However, the values of V and η are very sensitive to the mute function used for the first velocity picking. In the case of deep offshore data, it is usual to observe small errors in velocity causing erroneous η values. As a conclusion, one-parameter picking methods could provide excellent stacking parameters, but their "geological" meaning is doubtful. And that is valid for the RMS velocity as well as for effective η pickings. The simultaneous dense picking of V and η is the most convenient approach. In fact the effects of V and η on the moveout are not uniformly distributed along the offsets: the velocity affects all the offsets and the effect of the η is concentrated on far offsets only. Despite everything, in daily practice, the velocity is generally estimated by the measurement of the short spread curvature of reflections using "near" offsets only.

Siliqi (2001) proposed a practical way to perform bispectral analysis using the anelliptic shifted hyperbola moveout (e.1). The use of two effective velocities, one related to the near offsets (RMS velocity) and the next related to the far offsets (anelliptic velocity) allows the calculation of a homogeneous bispectral panel, and a smart inversion scheme for the interval parameters.

De Bazelaire and Viallix, (1994) showed that in fact all offsets can be used to estimate RMS velocity, if the moveout equation, employed for the velocity analysis, takes ray bending into account. Moreover, they demonstrated that using shifted hyperbola, the moveout correction could be transformed to an equation independent of t_0 and proposed an original automatic dense velocity analysis.

Automatic dense picking of V and η using uncorrelated parameters

Taking advantage of the shifted hyperbola shape of the moveout equation (e.1), we propose to describe it using two new parameters (figure 1): *dtn*, the time-delay at the largest offset and τ_0, the zero-offset time in shifted coordinates.

The parameterization of bispectral analysis with *dtn*, τ_0 offers a vast number of benefits:

Fast dense bispectral picking

The moveout corrections due to the *(dtn, τ_0)* pairs can be performed as static shifts (*t_0*-independent equations). The substitution of dynamic moveout correction by static moveout correction drastically reduces the time taken for velocity analysis and improves the quality of the spectra by avoiding the stretch at far offsets.

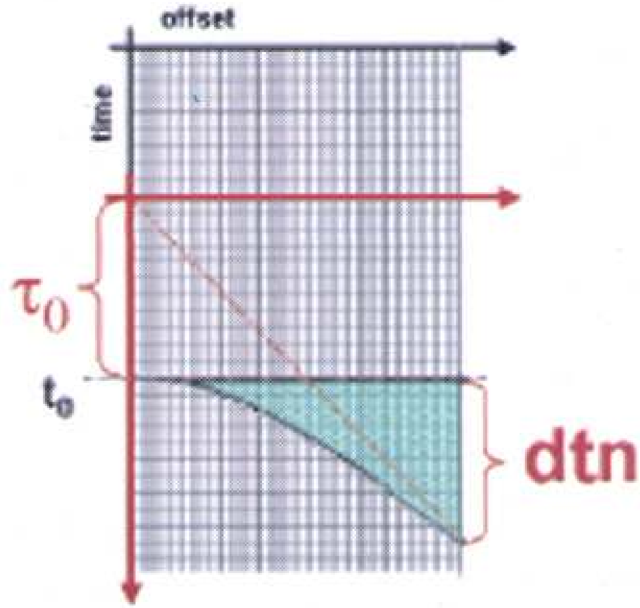

Figure 1 : New parameterization of shifted hyperbola moveout

Figure 2 shows the 3D spectrum of semblance obtained by the double scan *(dtn, τ_0)* through a real bin gather. This volume is the extension to two parameters of the conventional velocity spectrum panel. The automatic search for the maximum semblance per each t_0 allows continuous *(dtn, τ_0)* bispectral picking. Any pair is transformed to *V* and η. In fact *dtn* is a function of *V* and η, because it is not necessarily related to the hyperbolic shape of the moveout. On the other hand, τ_0 is a function of only η because τ_0 differs from t_0 only when the reflection curve is not hyperbolic.

"Orthogonal" parameters

The new parameters *dtn* and τ_0 seem to be uncorrelated, which is not the case for *V* and η. This feature is visible on the *(dtn, τ_0)* cross-plots of the residuals from the trend in the original picks (field data). Figure 3 illustrates the quasi orthogonality of the predictability axes between Δdtn and $\Delta\tau_0$ values. The same analysis performed on *(V, η)*

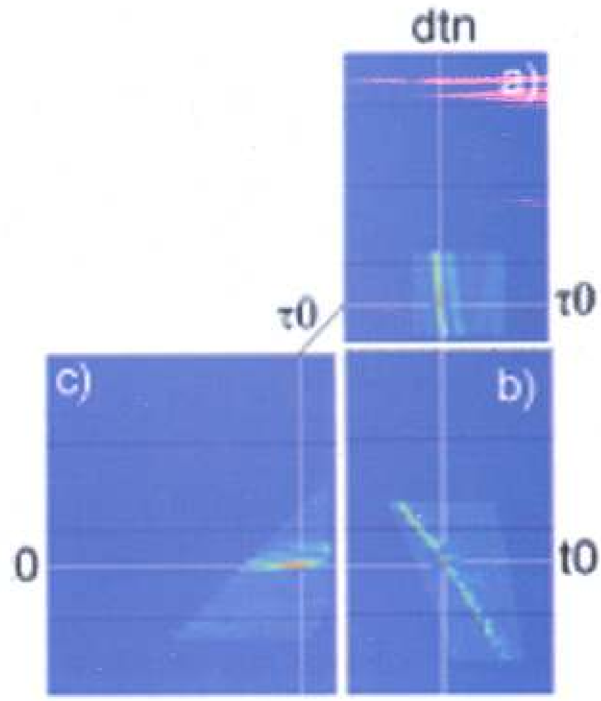

Figure 2: 3D analysis volume (t_0,dtn,τ_0) a) Bispectral (dtn, τ_0) at t_0 level b) dtn spectra for a constant value of τ_0

bispectral picking denotes the strong correlation between ΔV and $\Delta\eta$.

Velocity analysis to within the seismic resolution

Since the moveout effects and *dtn*, τ_0 values are both time quantities, the quality of the flatness can be as high as required. Consequently the accuracy of estimated *V* and η is completely under control. For instance, in the case where the required flatness error is less than *4 ms* at any offset, the velocity errors do not exceed *0.5% (2000 ± 10 m/s)* and η errors do not exceed *10% (0.150 ± 0.015)*

The results of the automatic dense picking contain more information than is required for the moveout process

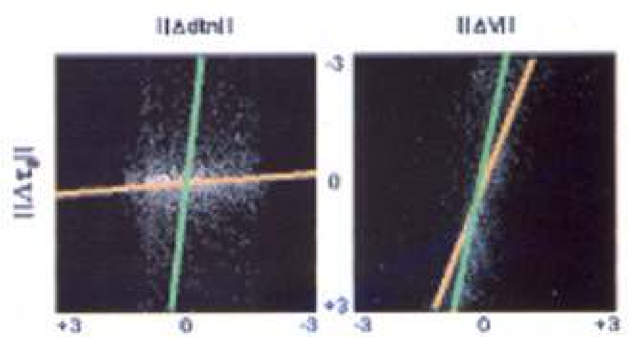

Figure 3: Centered and normalized cross-plots of residuals from the trend in the automatic picks a) picking of dtn, τ_0 pairs b) picking of V, η pairs. The two predictability axes are shown in colour

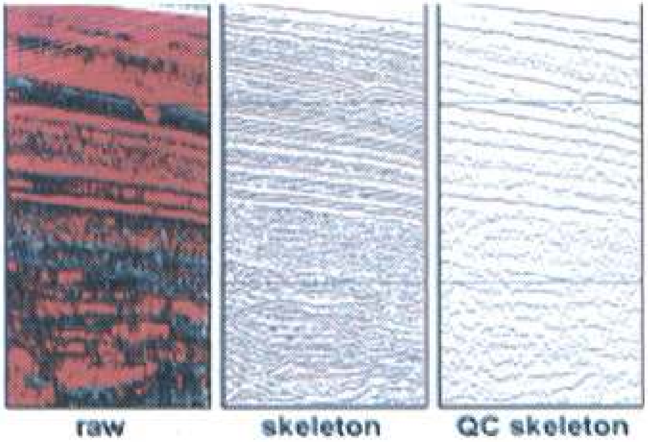

Figure 4: Output of automatic picking. Locations of (dtn, τ_0) pairs through the sorting process: from original picks to the final skeleton.

(more than one V-η pair per wavelet). Moreover V and η are locally estimated and some temporal and lateral inconsistencies may occur. To reduce the redundancy of the picks and increase their reliability, intelligent sorting is necessary. Figure 4 shows how the raw picks can be reduced to a skeleton, combining semblance value with the lateral coherency of the power stack. The reliability of the remaining (V, η) pair is certified by a series of Dix inversions between all pairs of the bin location.

Simultaneous filtering of V and η using uncorrelated parameters

Dense V and η fields, picked automatically, contain different information at different scales but at the same time they are contaminated by wrong values due to interference, multiples and artifacts. The filtering of these dense fields is necessary. Nevertheless the first step is to fill empty areas, where the automatic picking failed or various QCs based on lateral coherencies and Dix-inversion abilities removed values. V and η fields are simultaneously interpolated using their original decomposition into uncorrelated parameters. The filling of *dtn* and τ_0 is performed separately using the 3D ordinary kriging. Thanks to this technique, each data point is weighted according to its influence on the 3D neighborhood (Matheron, 1963).

The goal of the filtering step is to remove the non-geological features, which corrupt the full *dtn* and τ_0 fields. More advanced techniques, such as 3D factorial kriging, seem to be appropriate for this task. Separate modeling of the *dtn* and τ_0 3D experimental variograms allows filtering of outlier patterns and directional artifacts without harming the small-scale variations of these fields. The optimal filtering of these uncorrelated parameters corresponds to the requested simultaneous filtering of V and η. Figure 5 shows the results

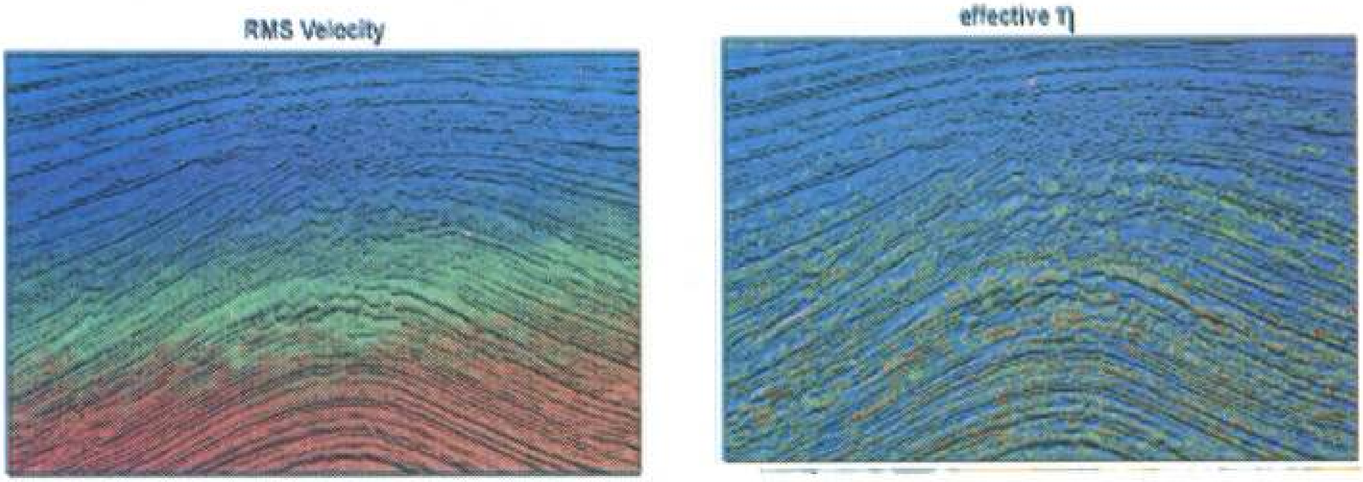

Figure 5: V and η dense fields obtained by the simultaneous picking and filtering process superimposed on thestack. The high value of η (right) follows the structures, which is not the case with RMS velocity colors (left).

of simultaneous picking, interpolation and filtering of V and η. Two typical types of behavior could be observed: if anellipticity follows the structures, the velocity contour lines are parallel to the water bottom, which is generally expected for RMS velocities. This observation attempts to prove the decoupling of velocity from the anellipticity (ray bending and/or anisotropy).

The key to this process is to pick geophysical attributes with little physical meaning (but they are conveniently orthogonal) and then to transform them into attributes that make geological sense. Indeed with this process the effects of anisotropy are effectively separated from the velocity estimation and the resulting fields make more geological sense. Furthermore, the gathers are almost perfectly flat (figure 6), which optimizes the stack and makes AVO analysis possible.

Figure 6: Corrected deep offshore bin gathersusing V and η dense fields obtained by thesimultaneous picking and filtering process.

Conclusions

Performing the focusing process using dense "geologically" meaningful parameter fields is the new challenge in time imaging. To achieve this objective we proposed in this paper an original automatic bispectral picking which is able to pick simultaneously in an uncorrelated way the two parameters RMS velocity and effective η. Both are estimated to within the seismic resolution. The search for lateral coherency in the pickings, combined with Dix-inversion capabilities, allows significant V and η skeletons, close to horizon-consistent pickings. The simultaneous geostatistical interpolation and filtering of these dense fields achieve the stated objective: performing the most accurate moveout through the use of meaningful parameters.

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