Multiple prediction without prestack data: an efficient tool for interpretive processing

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Introduction

Multiple-attenuation during data processing does not guarantee a 'multiple-free' final section. Although a great deal of effort has been given to the problem of multiple-suppression (Berryhill and Kim 1986; Wiggins 1988; Verschuur *et al.* 1992; and others), perfect solutions still do not exist. When the subsurface structure is complex, the remaining multiples will be difficult to recognize, especially after the data have been migrated. In addition, many of the available multiple-suppression techniques are restricted to two-dimensional geometries and do not attempt to handle interbed and complex multiples (which consist of a combination of interbed and surface-related multiples). These restrictions further increase the possibility of obtaining undesired multiple energy in the final sections.

Generally speaking, multiple prediction is used as an initial step for multiple suppression. The predicted multiples must be very accurate, both kinematically and dynamically, since the suppression operation involves subtraction of multiple energy from the recorded data. Therefore, standard multiple-prediction algorithms require manipulation of prestack data or an accurate forward-modelling technique based on a given interval velocity model of the subsurface.

While interpreting data from areas where significant multiple energy has been recorded, the interpreter must rely on the success of the multiple-suppression operation. When it is suspected that a certain event is a multiple, it is difficult to verify this using standard interpretation tools. We believe that multiple prediction and identification can play an important role in seismic interpretation. The main obstacle preventing multiple-prediction procedures from being routinely used by interpreters is the necessity to access prestack data.

Velocity analysis in an interpretive process that may become difficult to carry out in the presence of multiples (Gasparotto and Lau 2000). It is often the analyst's decision to distinguish between primary and multiple energy while picking velocities. If the multiple-prediction procedure can provide information on the velocity that will optimally stack the multiple energy, it could be used as a guideline during velocity analysis to help in avoiding erroneous velocity picks.

This study is based on the assumption that if the prediction is not aimed at providing input to multiple-suppression algorithms, then it can become a purely kinematic procedure. Furthermore, without prestack data, interactive algorithms, highly suitable for interpretive work, can be developed on the basis of the proposed procedure.

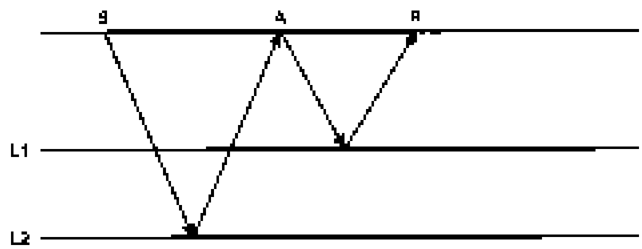

Figure 1a *Surface-related multiple path.*

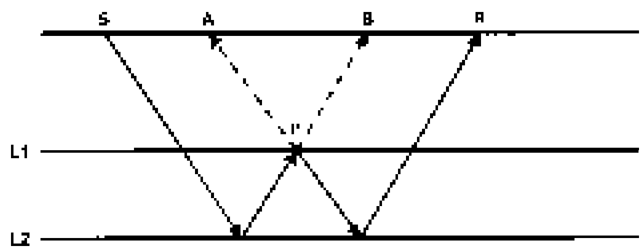

Figure 1b *Interbed multiple path.*

In the following, we briefly describe the concept of the prediction method. We then show how the need to access prestack data is avoided, thus permitting fast interactive prediction after stack and/or migration. Finally, we suggest a practical workflow to promote prediction during interpretation and standard velocity-analysis sessions. All the above procedures will be illustrated using synthetic and field data examples.

Prediction method

The multiple-prediction method is based on a simple concept: each multiple, regardless of its complexity, consists of segments that, from a surface perspective, are primary events (Keydar *et al.* 1998; Jakubowicz 1998). Figure 1 illustrates this concept and the definition of the multiple condition. A simple surface-related multiple is shown in Fig. 1a. In order

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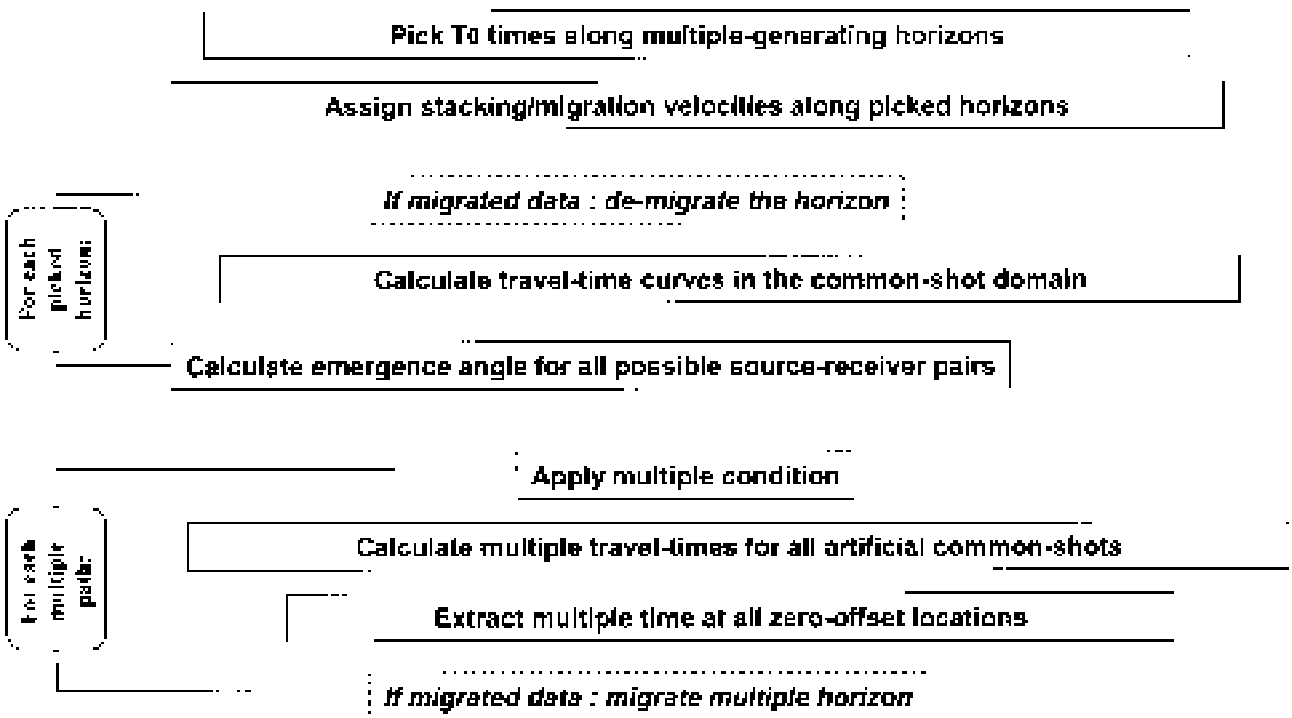

Figure 2 *Schematic workflow for multiple prediction.*

to calculate the traveltime of this multiple for a specific source–receiver pair (S and R in the figure), a surface point A is sought. At this point, the emergence angle of the ray representing the first primary reflection from the second interface L2 (S → L2 → A) must be equal and opposite in sign to the emergence angle of the ray representing the second primary reflection from the upper interface L1 (R → L1 → A). This equality is the multiple condition for a surface-related multiple and the multiple time is the sum of the traveltimes along the two primary segments.

When we deal with an interbed multiple (Fig. 1b), the calculations are a little more complicated (Keydar *et al.* 1998; Jakubowicz 1998). For a given source–receiver pair (S and R in the figure), two surface points, A and B, need to be defined. The surface emergence angle of the ray representing the first primary reflection (S → L2 → P → B) must be identical to the emergence angle of the ray representing the primary reflection for a source–receiver pair located at A and B, respectively (A → P → B). In addition, the emergence angle of the ray representing the second primary reflection (R → L2 → P → A) must be identical to the one representing a primary reflection from L1 (B → P → A). When this multiple condition is satisfied, the interbed multiple time is defined by the sum of the two traveltimes along the primary reflections from L2 minus the traveltime along the primary reflection from L1.

A multiple condition for more complicated multiple paths can be defined in a similar way (see Keydar *et al.* 1998). Note that these multiple conditions are accurate and do not involve any assumptions about the geometry of the reflection interfaces and/or the layer velocities.

In a previous study (Landa *et al.* 1999), a method to estimate the emergence angle from shot records was presented. Here, we use the same concept (Keydar *et al.* 1996), but instead of accessing the prestack data, we estimate the angle from 'fictitious' common-shot traveltimes. These traveltimes (related to primary events) are calculated using picked zero-offset times, stacking velocities and hyperbolic approximations in the CMP domain. We avoid the access of prestack data in the following way:

As a first step, *primary events,* suspected of being multiple-generators, are picked on a stacked or time-migrated section. Given the stacking or migration velocity function that was used to generate the section, prestack traveltime curves are calculated in the CMP domain for each primary event. Assuming that the surface velocity is known, these traveltimes are used to calculate emergence angles for each possible source–receiver pair in the common-shot domain (Keydar *et al.* 1996).

Angles that satisfy the multiple condition define the segments of the primary events that form the specific multiple. As we showed in the previous paragraph, the predicted (prestack) multiple traveltime is a simple sum of traveltimes along the primary segments.

Figure 2 illustrates a general workflow scheme of the technique. The scheme can be used for migrated or unmigrated data. When the zero-offset times are picked on a time-migrated section, two additional steps are required (indicat-

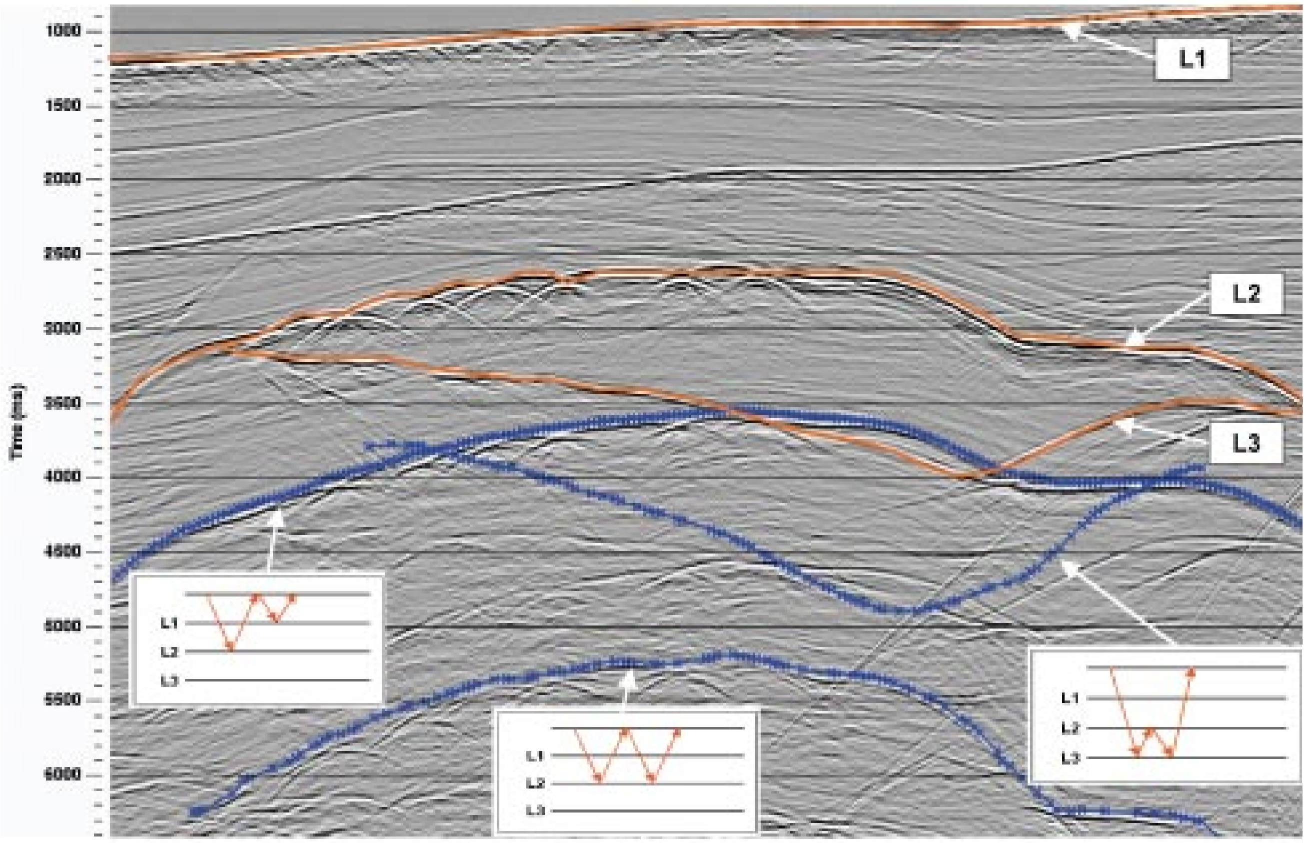

Figure 3 *Post-stack multiple prediction. Picked horizons (L1–L3) in red, predicted multiples in blue. Multiple paths are schematically represented in the white boxes.*

ed by dashed boxes in the figure). The first additional step is demigration of the picked horizons (Whitcombe 1994) before calculating the predicted multiples. The additional second step comes at the end of the procedure where the calculated multiple horizons are time migrated. In many cases, the multiple-generating horizons are well known (sea-floor, top/bottom of a salt body, top/bottom of a basalt layer, etc.). Other suspected horizons may be added or dropped in a trial-and-error manner. The stacking or migration velocities along these picked horizons can be accurately assigned by Horizon Velocity Analysis (Yilmaz 2001). Note that extracting the stacking velocities along the picked horizons from a global table obtained by conventional velocity analysis may reduce the accuracy of the prediction. Since prestack data is not used, the extent of the artificial common-shots (offset range and spatial decimation) can be defined as required. In other words, primary events are generated anywhere we need them, regardless of the acquisition geometry. It is, however, recommended that the maximum recording offset and the maximum recording time be used as limiting factors. The common-shot traveltimes should be generated for a split-spread configuration. This is necessary for accurate estimation of the zero-offset time of the predicted multiples. For data with long recording times, even a small number of multiple-generating horizons may produce many multiple paths. As indicated in Fig. 2, each multiple path is handled separately. The set of calculated zero-offset multiple times is used to generate a predicted horizon for each multiple path.

The accuracy of the method is directly related to the quality of the multiple-generator picking and the correctness of the assigned stacking/migration velocity along the picked interfaces. When the subsurface structure is complex and the primaries are non-hyperbolic, the artificial shot-records should be generated by forward modelling. In this case, the interval velocity model of the subsurface is required.

Examples

Figure 3 shows a part of the Pluto synthetic stacked section, released for research on sub-sea multiples by the SMAART JV consortium (*First Break* 2001). Three primary reflectors were picked on top of the section (L1, L2 and L3, marked by red lines in the figure). Many events are suspected multiples in the area between 3.5 and 6.0 seconds. Three multiple paths were predicted and are shown as blue lines in the figure. It is clear that the peg-leg and the surface multiple from the second primary reflector (L2) are strong events, while the interbed mul-

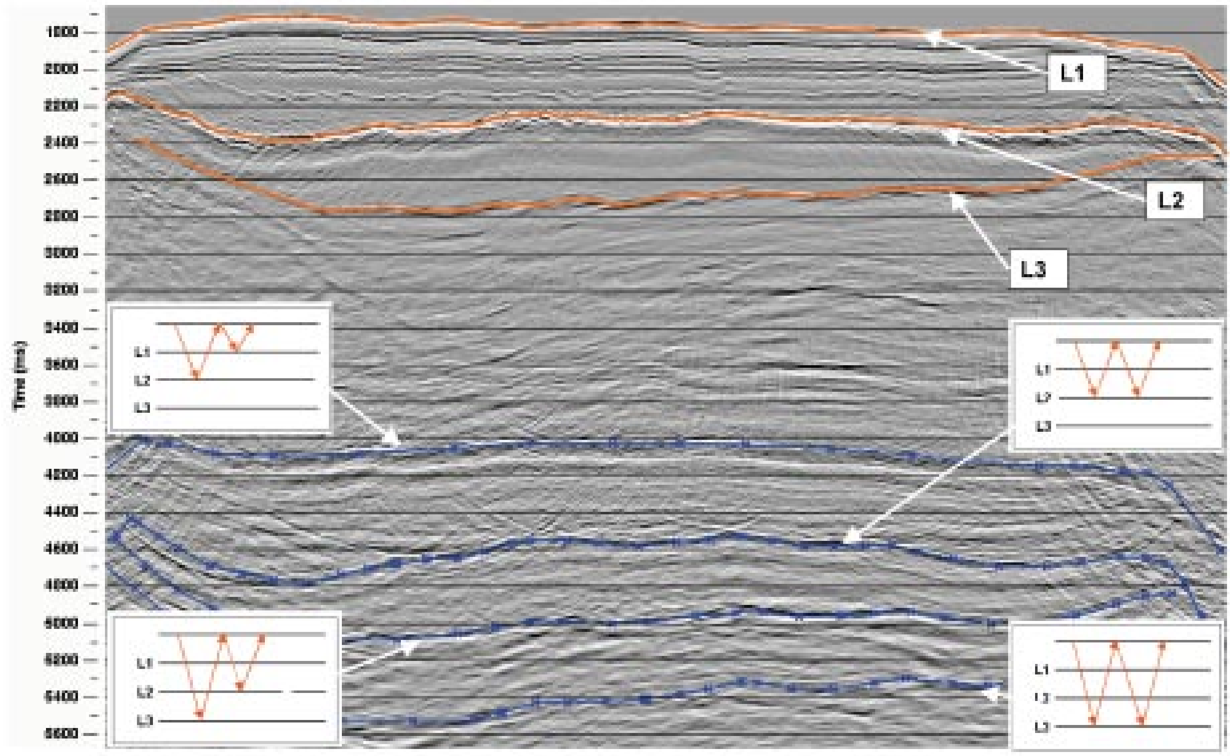

Figure 4 *Post-stack multiple prediction. Picked time-migrated horizons L1–L3) in red, predicted (and time-migrated) multiples in blue. Multiple paths are schematically represented in the white boxes.*

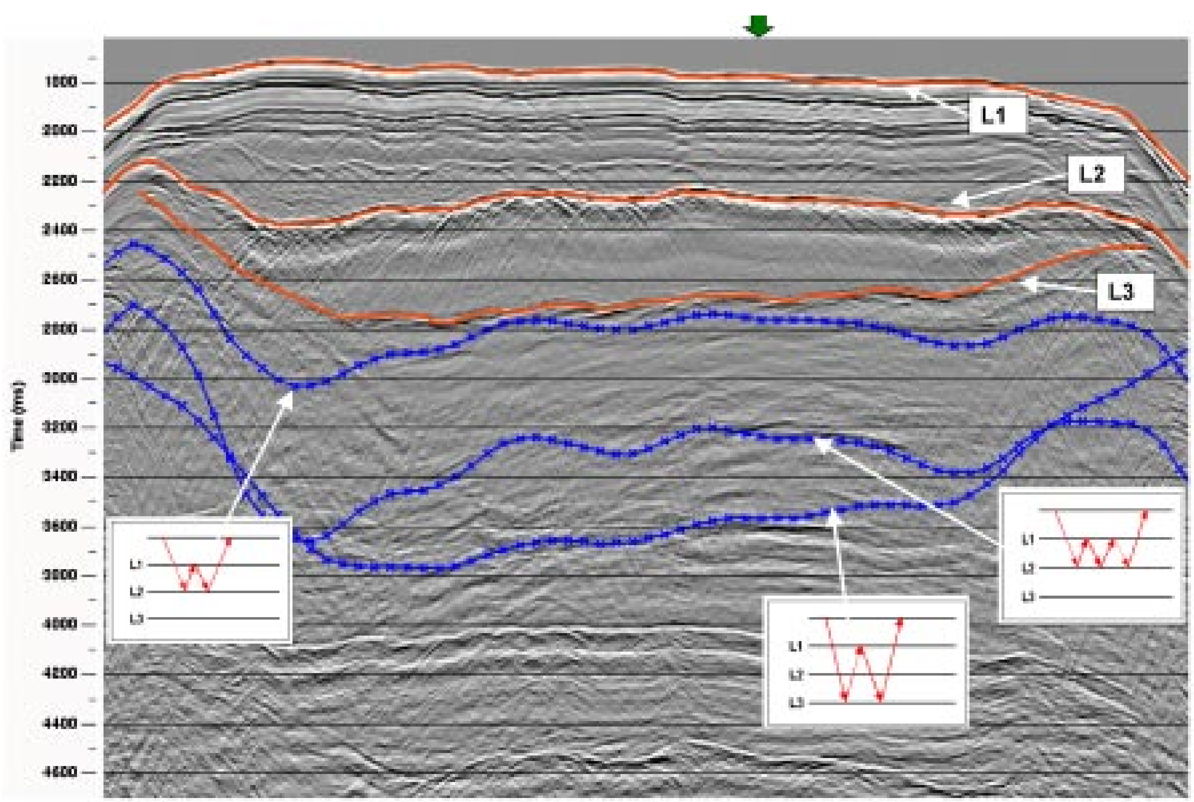

Figure 5 *Interbed multiples. Picked horizons (L1–L3) in red, predicted multiples in blue.*
Multiple paths are schematically represented in the white boxes. The green arrow on top marks the location of the velocity analysis shown in Fig. 6.

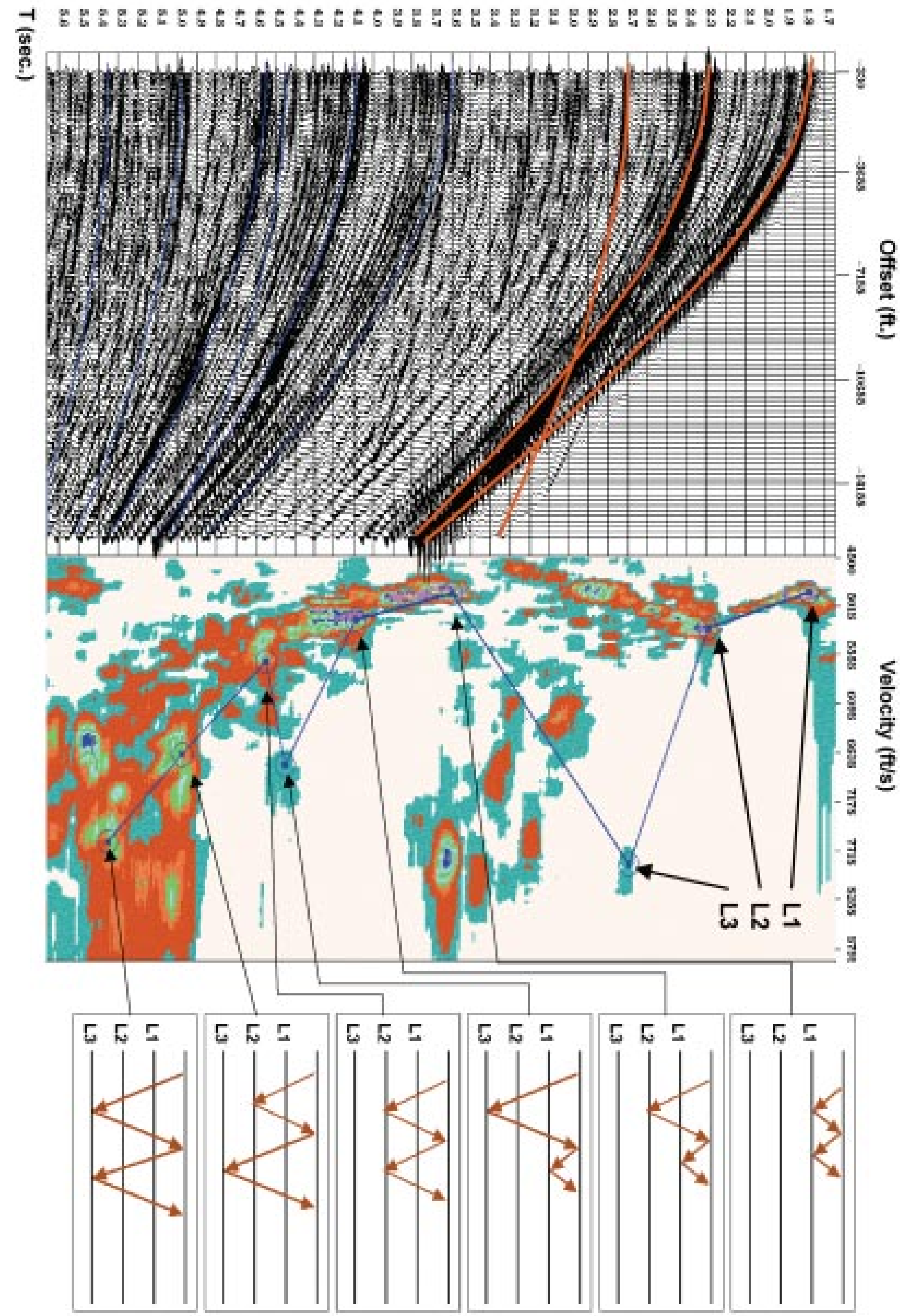

Figure 6 *Velocity analysis (see location in Fig. 5). (a) Three primaries and a few predicted surface-related multiples are shown in blue. The multiple paths are graphically represented in the white boxes on the right.*

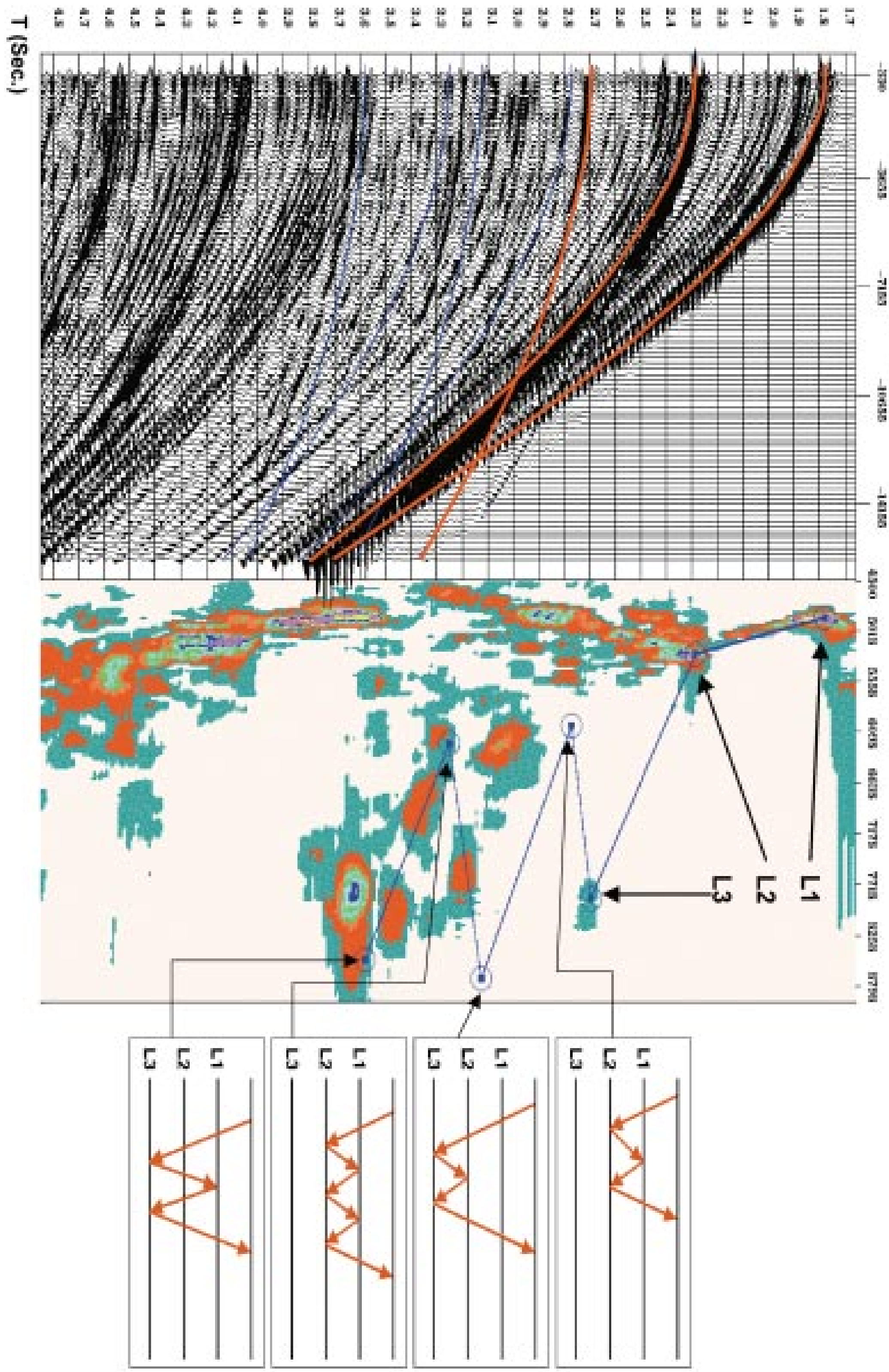

Figure 6 *b Three primaries and a few predicted interbed multiples are shown in blue. The multiple paths are graphically represented in the white boxes on the right.*

tiple does not appear to have significant energy in the section. The figure indicates that although the predicted multiple reflections are not perfectly aligned with the events, the overall match is good and can definitely be used for interpretation.

In most situations, interpretation is performed on migrated sections. Figure 4 represents a time-migrated section of a marine dataset. Three horizons were indicated as multiple-generators (L1, L2 and L3, marked by red lines in the figure). Using the migration velocity, the horizons were demigrated and a few multiples were predicted. The results are shown in blue, after being time migrated (see schematic flow in Fig. 2). The additional operations of demigration and migration usually increase the inaccuracy of the prediction. However, for moderate structures, as in this example, the overlaid results show a good match with the migrated data.

Interbed multiples are not usually handled by standard multiple-suppression techniques. In many situations they may interfere with primary events. Figure 5 demonstrates how the prediction method is used to check whether interbed energy is significant. Three horizons (shown in red) were picked on a stacked section. Three predicted interbed multiples are plotted as blue overlays on top of the section. Although the predicted horizons overlap a few segments of strong and coherent energy, our interpretation suggests that the interbed energy in this example is insignificant.

Velocity analysis in the presence of multiple energy can lead to errors in the output velocity function. When the multiple events have a moveout velocity significantly different from the moveout of the primaries at the same T_0, it is relatively simple to identify them during a velocity-analysis session. Short peg-legs, interbed and other complex multiples may have a moveout velocity similar to the velocity of the primaries.

In this study we use the predicted multiples to aid the processor in the velocity-analysis procedure. After the multiple has been predicted, we try to fit an optimal hyperbolic curve to the predicted traveltime. This optimal fit is translated into the stacking velocity of the specific multiple path. During a velocity-analysis session, the predicted multiple velocities can be displayed as markers indicating where the undesired multiple energy occurs. Figure 6 demonstrates the procedure. A CMP location was selected from the dataset shown in Fig. 5 (the location is marked by a green arrow on the figure). As a reference, we show the velocity picks for the three primary reflectors on top of the velocity semblance display. The hyperbolic curves are shown in blue on top of the CMP data (left-hand side of the figure). Figure 6a shows the velocity estimate of six surface-related multiples. The multiple paths are schematically represented in the boxes on the right. Starting with the first layer's multiple (at 3.6 s), we can see that multiple energy dominates the data from 3.6 to 5.4 s. The estimated multiple velocity matches the hyperbolic data in this region well and the picks are located on the related semblance maxima. In Fig. 6b, velocity estimates for four interbed multiples, all having traveltimes shorter than the first surface multiple, are shown. The traveltimes of these multiples indicate that they may interfere with primary events, just under the third layer (see also Fig. 5). In addition, their velocities are similar to the velocities of the primary events. However, a careful look at the location of the multiples' velocities on top of the semblance display and the related hyperbolic curves on top of the data suggests that they do not follow coherent events. This type of analysis, together with the horizon overlays of the interbed multiples (see Fig. 5), can strengthen the conclusion that significant multiple energy does not exist between 2.7 and 3.6 s. The strong and coherent events in this time region can be picked as primaries.

Conclusions

An interactive method of predicting multiples was presented. The method is target-orientated and it does not require access to prestack data or detailed knowledge of the geological subsurface model. The kinematic nature of the method and the fact that it does not require access to prestack data are used to build helpful applications for interpretive processing.

For the purpose of interpretation and under the assumptions and limitations of time-domain processing, we believe that the method presented here offers adequate accuracy and computational efficiency. The use of a more complete wave-theoretical approach for the prediction may offer more accurate results but will introduce a significant increase in computer time.

The proposed method can be extended to 3D. In this case, it will be necessary to estimate the three-dimensional emergence angle for each source–receiver pair. The ability of the method to produce multiple times for any offset, may become useful in the process of 3D multiple suppression.

Multiple prediction for multicomponent data can be developed on the same principle by defining a separate condition for each mode-converted path.

In complex geological areas, where the primary reflections are significantly non-hyperbolic, the emergence angle cannot be estimated by the proposed scheme. In this case, the angle should be calculated by forward modelling (ray tracing for instance), assuming that the correct interval velocity model is known.

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