A precise method for matching well data with 3D time migrated seismic data.

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Summary

Up to now the integration between VSP and time migrated data is performed in two separate stages. Primarily we process the VSP and only after this we try to position it inside a 2D or 3D seismic image. A new method is proposed for doing this in one single step. A by-product of this is a true 3D time migration of the VSP. Applying this method on real data demonstrates its precision. The fit between VSP and time migrated data is very good and we have a phase to phase correlation. Moreover, this correlation is very good not only at the edges of the VSP section, but throughout it.

Introduction

The integration of well data and time migrated seismic data is a very important stage during the seismic interpretation. It can be also a very frustrating one because of the poor match between these two kinds of data. The most important and in the same time, the most difficult step in this integration is the calculation of the well trajectory in the time migrated domain. A wrong trajectory will surely lead to a poor match and will diminish one's confidence in the interpretation work. Why is this so difficult? All that we have to do is to transform the depth trajectory of the well (that we know very well) from the depth domain to the time domain. In other words, the question that we have to ask is the following: 'Can we pass from the depth domain to the time migrated domain in a precise way?' The answer to this question is 'yes' (Raynaud and Thore 1994, Kaculini 1994, Sexton and Robein 1996) and this gives us the necessary means for the integration of well and time migrated seismic data. Let me give first, a quick overview of different methods used for the calculation of the time migrated trajectory of a well.

The most simple (and the most used one) consists in obtaining the time migrated trajectory by vertically stretching the depth domain one. As a result, the shape of the trajectory in both domains will be the same. But we know that the relation between these two domains is not so simple. As a consequence, in the presence of dips and lateral velocity variations this method is a very crude approximation and will not permit to obtain good results.

A more precise method is the use of image ray theory. Compared to the vertical stretching, this is a better approach, but the situations where we can use it are limited. Its limitations are the same as the limitations of image-ray theory. Moreover, it does not take into account the time migration velocity used during the processing. It means that whatever the velocity used for the time migration, the time domain trajectory of the well will be always the same and will depend only on the depth velocities. In summary, using this method we try to fit two kinds of data, one which is a function of the time migration velocity and another one that is independent of it. No surprise that the match is poor.

A precise method for transforming the data from the depth domain to the time migrated domain consists in carrying it out in two steps. In the first step the data are transformed from the depth domain to the stacking domain using normal ray tracing. In the second step time migration is simulated using the same velocity that is used during the processing of the seismic data. The success of all this depends on how effective is the second step or in other words, how well we can simulate the time migration. Kaculini (1994) has shown that we can simulate 3D-time migration in a precise and efficient way using Kirchhoff migration modified to take into account lateral and vertical variations of time migration velocity. So using this approach we will have no difficulty to calculate precisely the well trajectory in the time migrated domain (Robein and Kaculini 1995, Robein and al 1995). As explained above, this will be carried out in two steps. In the first step, a normal ray is sent from the intersection of the horizon with the well trajectory and in this way the stacking position is restored. In the second step the time migration is simulated. In theory, this has to be done for every point of the trajectory. In practice, it is sufficient to do this only for the intersections of the well with main reflectors.

It is interesting to stress that the difference between depth and time migrated trajectory can be very large. This of course, is data-dependent and has to be assessed for every particular case. Gancarski and Kaculini (1994) reported distances up to 500m between two trajectories. It is clear that if this is not taken into account, one can not expect to have a good fit between seismic and well data.

VSP time migration

Up to now the match between time migrated seismic data and the VSP is always carried out in two separate stages. Primarily we process the VSP and only after this we try to position it inside a 2D or 3D seismic image. There are no objective reasons why not to do all this in one single step. All we have to do is to find the relation between the 'VSP' domain and time migrated domain. If this relation or function is found what remains to be done is just to pass each point of the VSP from one domain to the other. Moreover if during this calculation we use the same velocity that is used for the time migration of the surface seismic data, both kinds of data will be migrated in exactly the same way and will fit perfectly (if we still have matching problems it means that our depth model is not exact and we have to integrate in it our well data). So what remains to be done is to show how we can pass the data directly from the 'VSP' domain to the time migrated domain.

The idea is to pass the data successively from the 'VSP' domain to the stacking domain and at the end to the time migrated domain. This will give us the required relation between 'VSP' domain and time migrated domain. All these calculations will be done in 3D and in consequence the positioning of the 'VSP' data in the time migrated domain will be more exact than in the case of conventional processing where all VSP data are forced to stay in the plane.

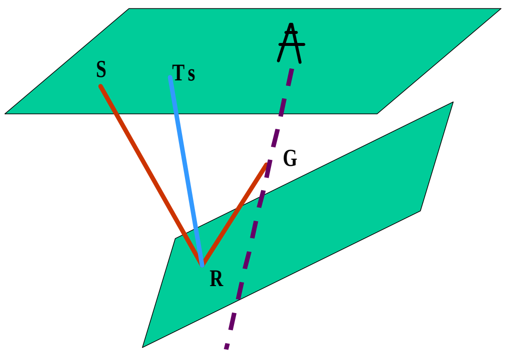

Figure 1: Using ray tracing, the reflection point R on the reflector is found for every couple source-recepteur.

The principle of the method is shown in Fig. 1. Let's assume that we have already built a depth velocity model (for the simplicity in Fig. 1 is shown only one layer) and put in it the well trajectory. Using ray tracing, the reflection point R on the reflector is found for every couple source-receiver. A normal ray is sent from this point (R) to the surface. This gives us the coordinates {Xs, Ys, Ts} of the point R to the stacking domain. The time migration of this point can now be performed (Kaculini 1994), using the same velocity that we used for the migration of the seismic data. So after all this we have the following relations:

{Xvsp, Yvsp, Tvsp} → {Xs, Ys, Ts} → {Xm, Ym, Tm}.

These relations enable us to pass every point, every amplitude of the VSP to the time migrated domain or in other words to migrate it. However, this kind of migration is different from what is done normally by conventional processing methods. Points are passed independently from 'VSP' domain to the time migrated domain and as a result, in the time migrated domain, we will have a set of points instead of traces. Moreover this set of points is distributed in a 3D volume, so some cosmetic processing like resampling and interpolation, has to be applied. The final result of all this will be a 3D time migrated VSP cube. After this we will have no problems mixing VSP and time migrated data; both kinds of data have been migrated in the same way, using the same velocity and even in the case that time migration has failed, it has failed in both cases, in the same way.

Example

This method is applied to a real data case. The idea is to integrate the VSP data with 3D time migrated data. Prior to this, the major reflectors were identified and picked in the time migrated cube. A 3D-velocity model was built using these picks and regional velocity information. Slight modifications of the velocities were needed for some layers to obtain a fit between interface and well depths. It is important to stress that only the up-going wavefield of the VSP is used.

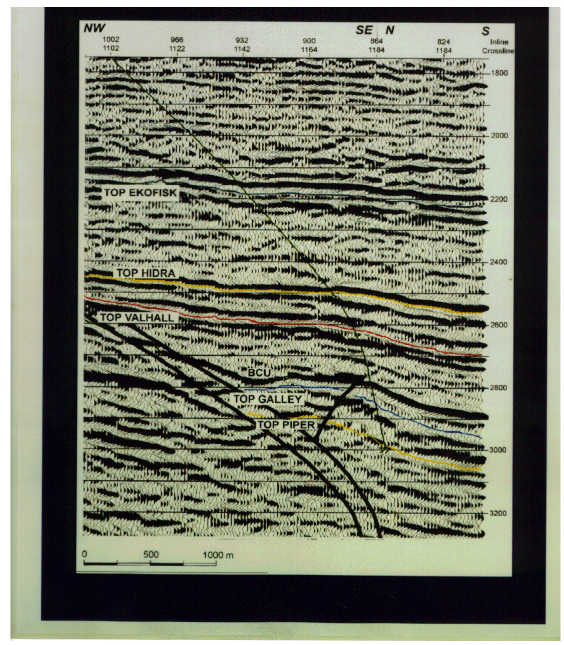

Figure 2: Random line in time migrated domain passing by the vertically stretched well trajectory.

Using this depth velocity model, the method described above was applied. The goal was to compare this method with a conventional processing and fit of the VSP with time migrated data.

On Fig. 2 we present a time migrated random line that passes by the vertically stretched well trajectory. This kind of random line is normally considered as the best seismic section to be used for the integration between well and seismic time migrated data. On Fig. 3 we present the same section mixed with a conventionally time migrated VSP. Comparing these two images one can notice that the fitting between the VSP and the seismic is not very good. The phases of major reflectors on the VSP and seismic section are not the same. Moreover, the dips of the reflectors on both sections at the BCU level are contradictory.

Figure 3: Random line with VSP conventionally time migrated on it.

Let's now apply the method described in the main text to the same data and see if we have any improvement. On Fig. 4 we present the equivalent of Fig. 3, but now we have done a real 3D time migration of the VSP. On this figure the VSP data are presented in color and on the background we can see the time migrated data in black and white. It is obvious that now we have a perfect fit between well and seismic data. The two kinds of data fit very well not only at the edges of the VSP section, but all throughout it and we have a perfect phase to phase correlation. It is important to stress that the depth velocity model used for these calculation permits to go up to 3sec, so the velocity used after this limit is approximate. Further picking of deeper reflectors will be needed to have a more precise result in bigger times.

It is interesting to identify on the VSP section the different reflectors of the depth model. Of course, this can be done automatically during the calculation. The result is presented on Fig. 5. On this figure the direct arrival is shown on red and all other reflectors in different colors. What is shown in this figure is what one has to pick on the VSP section in order to build the same depth model that was build using seismic data only. This gives the possibility to assess the validity of the depth model using an independent kind of information that is not taken into account during the building of the model. It will show which details present in the VSP data have to be incorporated in the seismic depth model in order to make it more accurate.

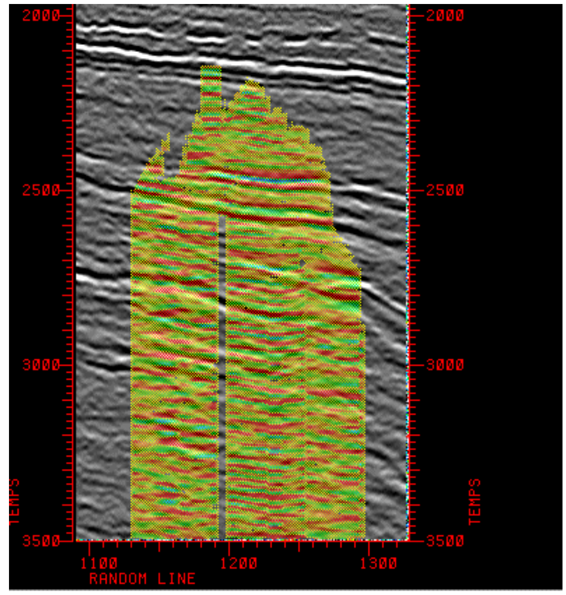

Figure 4: Random line with 3D time migrated VSP on it.

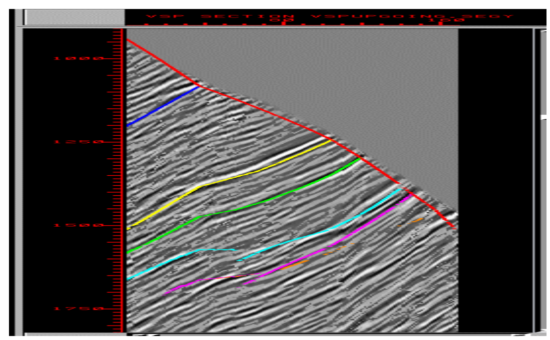

Figure 5: VSP section.

Conclusions

The match between well and time migrated data is an important step of seismic interpretation. In the case of poor match, the tendency is to say that the cause of this is poor processing of one or the other kind of data; or both of them[1]. Frequently the reason can be quite different. I show here a new method to handle this integration. A 3D time migration of the VSP data is carried out using the same velocity used for the migration of seismic data and simultaneously their positioning inside a seismic block is performed. The application of this method on real data shows a very good fit between VSP and time migrated seismic. Compared to conventional methods we notice a drastic improvement of the quality of the match. A by-product of the method is a 3D VSP time migrated block. So one will have more possibilities on choosing random lines for a better interpretation.

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[1] In the case of 2D VSP, the processing keeps the data in one single plane, which is a very crude assumption in the presence of lateral and vertical variations of the velocity. Of course, this will not help matching between VSP and time migrated data.