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Enhanced Velocity Modeling for a Geothermal Project in the Southern Vienna Basin - A Stacking Velocity Approach

C.G. Eichkitz* (Joanneum Research Forschungsgesellschaft) & J. Amtmann (Joanneum Research Forschungsgesellschaft)

SUMMARY

Velocity models can be build based solely on or from a combination of checkshots, VSPs, sonic logs or seismic stacking velocities. Depending on the information available, the method of building a velocity model can vary (using interval velocities, average velocities, layer cake model, V0-K method, models based on geostatistical methods ...). The advantages and disadvantages of these methods have been described by numerous authors.

In the course of a geothermal project in the southern Vienna Basin, the problem of a time to depth conversion arose. In the area of interest, only six wells with checkshot-information were available and, therefore, the usage of a simple V0-K method or layer cake method was not suitable. Hence, the application of available seismic stacking velocities for velocity modeling was tested. The stacking velocities were converted into interval and average velocities using the Dix equation. These velocity values were then sampled into a geo-grid and spatially distributed in the grid using geostatistical methods. The stacking velocities were compared where checkshots or sonic logs were available. The result of this velocity modeling procedure was a 3D velocity cube that can be used to depth convert the seismic profiles and the interpretation from the time domain.
Introduction

Velocity models can be build based solely on or from a combination of checkshots, VSPs, sonic logs or seismic stacking velocities. Depending on the information available, the method of building a velocity model can vary (using interval velocities, average velocities, layer cake model, Vo-K method, models based on geostatistical methods ...). The advantages and disadvantages of these methods have been described by numerous authors.

In the course of a geothermal project in the southern Vienna Basin, the problem of a time to depth conversion arose. In the area of interest, only six wells with checkshot-information were available and, therefore, the usage of a simple Vo-K method or layer cake method was not suitable. Hence, the application of available seismic stacking velocities for velocity modeling was tested. The stacking velocities were converted into interval and average velocities using the Dix equation. These velocity values were then sampled into a geo-grid and spatially distributed in the grid using geostatistical methods. The stacking velocities were compared where checkshots or sonic logs were available. The result of this velocity modeling procedure was a 3D velocity cube that can be used to depth convert the seismic profiles and the interpretation from the time domain. To visualize uncertainties in the velocity modeling, the depth converted horizons were compared to available well tops.

Velocity modeling

The input for velocity modeling can be checkshots, VSPs, sonic logs or seismic stacking velocities. Checkshots and VSPs measure average velocities. Sonic logs measure the interval slowness in the vicinity of the borehole. These measurements might be influenced by bad borehole conditions and may, therefore, not represent the actual velocities (inverse of measured sonic slowness) of the rocks. Seismic stacking velocities are basically processing velocities (Al-Chalabi, 1994), which can be converted into interval and average velocities using the Dix equation. This equation is only suitable assuming flat, isotropic and constant lateral velocity layers of the subsurface (Dix, 1955).

Based on these different kinds of input data, several ways of building a velocity model exist. The simplest method would be the usage of a layer cake velocity model, where each unit is treated separately (Marsden, 1989). The Vo-K method (Marsden, 1992, Smallwood, 2002) is a good way if good well control is available and if velocity increases linearly with depth. If the crossplot of velocity versus depth is scattered, which is often the case, then this method should not be applied. A good way to model spatial distributions in the velocity model is the usage of seismic stacking velocities in addition to velocity information derived from well data (Coleou, 2001, Veeken et al., 2005). In the course of this project, stacking velocities were used to get the spatial distribution of the velocity field and checkshots and sonic logs were used to determine the exact value for velocity. Velocity models can either be based on interval velocities or average velocities. For the development of a velocity model with interval velocities, accurate interval velocities from top to the bottom of the model need to be known. Often checkshots do not have many time-depth pairs for the shallow part and even in deeper parts, the distance between points of measurements are too high for an accurate determination of interval velocities. Average velocities can directly be calculated from the time-depth pairs of checkshots and VSPs. Converting seismic processing velocities to average velocities may still be arguable, but less so than converting these values to interval velocities (Bartel, 2006). The usage of average velocity also has the advantage that deeper time-velocity pairs are not affected by wrong velocity calculations above or by overburden velocity anomalies.

Case study southern Vienna Basin

For a geothermal study in the southern Vienna Basin, several 2D seismic reflection lines were interpreted in the time domain. In the area of interest, only six wells with checkshot data and some older wells with sonic logs were available. With this poor well control in the study area, it was hardly possible to develop a velocity model using the Vo-K method. Several of the seismic profiles (measured between 1967 and 1997) were available in digital version as well as print outs from the seismic processors. With the help of the plots, it was possible to get the velocities used for stacking the seismic. These time-velocity pairs were georeferenced using the known CDP coordinates.
Figure 1 shows an overview of the project area with model boundary, seismic lines, wells (only six of them had checkshots) and the position of known stacking velocities. 

![Figure 1](image1)

**Figure 1** Overview on the project outline in the southern Vienna Basin. The red lines indicate the available digital reflection profiles. The green dots show CDP-positions with seismic stacking velocities. The blue dots are all available wells in the area under investigation. The yellow polygon gives the model boundary for the velocity modeling process.

The stacking velocities were converted into interval and average velocities using the Dix equation (Dix, 1955). For the velocity modeling process, only the average velocities were used. The quality control of the converted average velocities was done by use of a simple crossplot technique (depth versus velocity), where outliers can immediately be identified, and by additional manual editing of the data points. In figure 2A, the available average velocity points after editing are shown. These data points were upscaled into a regular grid with 500 x 500 x 50 m cells. Geostatistics was used to get a spatial distribution of the average velocity for the whole model and for a final removal of noise in the data.

![Figure 2](image2)

**Figure 2** (A) Seismic stacking velocities for the area of investigation. These points were manually checked for outliers and afterwards upscaled into the velocity grid. (B) Velocity property model for the southern Vienna Basin. The upscaled points from (A) were spatially distributed using the Kriging method.

This velocity model derived solely from stacking velocities (figure 2B) was compared to the velocities from checkshots and/or sonic logs where available. With the difference between these two...
kinds of velocities, a difference property model was created and afterwards added to the stacking velocity model. The general workflow for the velocity modeling process is shown in figure 3. From the final combination of stacking and difference velocities, a velocity cube was calculated for a visual quality control (figure 4).

![Diagram](image)

**Figure 3** General workflow for the velocity modeling process.

The last step was to use the velocity cube for depth conversion of interpreted horizons. The horizon depths were compared to the well top depths and uncertainties calculated. In a future step, these uncertainties will be used for a correction of the velocity field in certain areas to enhance the time-depth relationship in the whole project area.

**Conclusions**

Time to depth conversion is one of the essential things in an exploration study. In an area where hardly any wells with "hard" velocity data (checkshots, VSP) are available, it is difficult to build a velocity using the $V_0$-K method. With the help of available seismic stacking velocities, we could develop a 3D velocity model with a reliable spatial distribution of the average velocities. The final velocity model showed good comparison with the available well tops. The combination of seismic stacking velocities and well log information based on geostatistical methods is a perfect tool for minimizing errors in time-depth conversion. Geostatistics proved to be a good tool to get spatial distribution of velocities. To get a precise velocity model, it is necessary to make a huge effort on the quality control and editing of the input data.
Figure 4 Final velocity model for the southern Vienna Basin derived from the velocity property model.

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References


