A strategy to image tectonically complex areas using CRS stack and prestack depth migration

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ABSTRACT

We produce depth images and an interval velocity/depth model for the DOBREflection 2000 line by using a strategy which includes the model-independent CRS stacking and iterative prestack depth migration and velocity analysis techniques. In imaging steeply dipping layers of thrust belt data, it is apparent that Foldbelt geology can violate the conventional assumptions of common midpoint (CMP) stacking thus, making velocity analysis to be tedious. To circumvent these problems, we first use the velocity model-independent CRS stack method to produce high quality unmigrated stacked images. Because the CRS results are purely data driven and no macro-velocity model is explicitly required, the use of a velocity model in the processing flow is "postponed" until later, when prestack depth migration (PSDM) is performed. Main horizons in the CRS images are interpreted and used for estimating the initial velocity/depth model. We couple PSDM with continuous adjustment of velocity/depth models. Careful examination of the common reflection point gathers lead to precious information about the local modifications to be made to the horizon velocities.

INTRODUCTION

A description of the DOBREflection 2000 dataset in terms of acquisition, geologic setting and seismic data processing is given in Menyoli et al. (this volume). In such complex tectonic areas, the conventional processing based on the concept of the common midpoint stack does not yield satisfactory results. This is because usually the assumptions of common midpoint traces are violated. Therefore, conventional processing up to poststack time migration is only used to obtain at an initial macro-velocity model (Fagin, 1998; Marschall and Thiersen, 1991). In this paper, in order to estimate the initial velocity/depth model, we follow a strategy which includes CRS stacking, poststack time migration and coherency inversion. The process of CRS stacking and time migration have been documented in Menyoli et al. (this volume). Therefore, we will only briefly discuss coherency inversion and we will emphasize on how to upgrade the initial model. We will show two workflows which were used to achieve our objectives. The workflows are flexible such that additional steps can be easily integrated.

IMAGING PROBLEMS IN THE FOLDBELT AREA

Figure 1 shows an example of a Foldbelt model which is typical along the DOBREflection 2000 line. In this figure the layers are disrupted by major and minor faults, some of which appear on the earth's surface. The layers are back thrusted thus showing some inversion in the sedimentary layering. Steeply dipping layers outcrop at the surface, thus producing strong lateral velocity variations and out of plane reflections. Such steep dipping events and the lateral velocity variations are problematic for conventional CMP stacking and poststack migration. First of all the assumption of having common reflection point (CRP) traces will be violated and the picking of reflection events during stacking velocity analysis will be difficult and tedious. The reflected waves from different reflection points will lead to a poorly interpreted stacking velocity field.

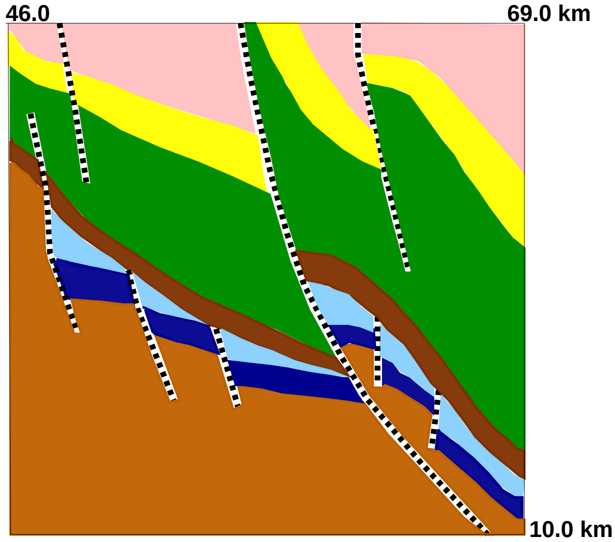

Figure 1: An example of a thrust belt model showing thick faulted layers and inversion. Because of the backthrust and inversion strong lateral and vertical velocity variation exist in the subsurface.

A poorly interpreted stacking velocity field will result in failure to optimally stack the data with loss of valuable signal and subsequent mispositioning when the data are imaged later. Poorly stacked images will eventually lead to poor poststack migration results since the success of poststack migration (time or depth) strongly depends on the quality of the unmigrated stacked section rather than on the accuracy of the migration root mean square velocity. Figure 2 is an example of a section, alone the DOBREflection 2000 line, after applying conventional stacking and poststack time migration. We anticipate that the poor image quality in this figure is partly due to the above mentioned problems. To obviate the above difficulties

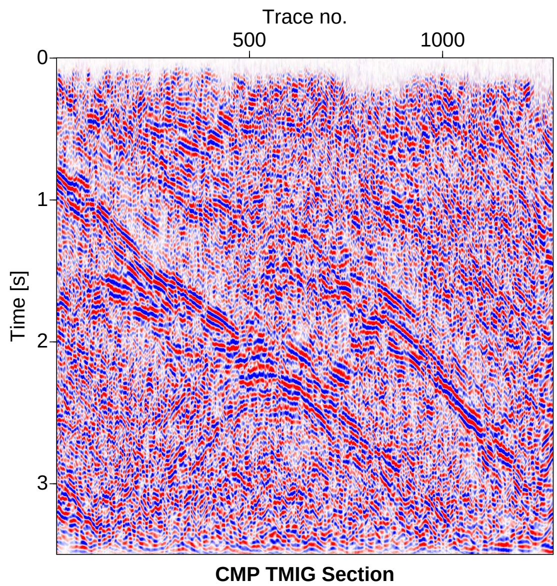

Figure 2: Poststack time migrated image after applying conventional stacking. Apart of the major reflector which is disrupted by a fault line, other reflectors are poorly imaged.

in such areas, prestack depth migration (PSDM) is usually the preferred imaging tool. However, PSDM requires a velocity/depth model and the success of PSDM strongly depends on the accuracy of this model. We will show a strategy how we obtained the velocity/depth model for the DOBREflection 2000 line.

As an input to PSDM, two types of macro velocity models are generally in common place. They are categorised as structural models and smooth models. Structural models are a set of surfaces that separate geological macro-layers and major faults. As such, these surfaces coincide with the main vertical velocity contrasts within the model. Because of the geological age of the sediments in the survey area, we preferred to use structural models as input into PSDM for this data set.

METHODOLOGY

Our strategy for estimating the velocity depth model for the DOBREflection 2000 line was based on four steps:

1.) Poststack time migration of CRS stack images and interpretation of main horizons in the time domain.
2.) Prestack depth migration (PSDM) using an initial velocity model obtained from coherency inversion and the interpreted time horizons.
3.) Iterative and interpretive adjustment of the velocity/depth models for optimising prestack depth migration.
4.) Structural interpretation of the prestack migrations during the iterative process and constrained by the surface structural geology model.

In Menyoli et al. (2002) (also see WIT report this volume) it was demonstrated that for the DOBREflection 2000 dataset, poststack time migration of CRS stack images gave superior results as compared to time migration results after conventional CMP stacking. Therefore, in order to estimate the initial velocity model, we interpret the main horizons on the high quality migrated CRS images. Figure 3 and 4 show examples of this interpretation. Note that, using the CRS stacking tool in order to generate a coherently stacked section avoids the problems of using wrong stacking velocities and thus "pushes" the use of velocity only for the depth conversion phase. The reflector continuity and high S/N-ratio simplify the horizon interpretation. Figure 3 clearly shows in detail the orientation of reflector dips and the main backthrust zone. The dipping reflectors and additional fault systems are easily interpretable. The interpretation show a rifted Devonian basement, overlain by rifted and folded Carboniferous sediments. After interpreting the time horizons, the velocities within the layers are estimated via coherency inversion (Landa et al., 1988) and the layers in time domain are finally ray migrated to their depth positions. In this way an initial velocity/depth model is estimated. The flow chart for estimating the initial model is shown in Figure 5. It has been shown in the work of Landa et al. (1988) that coherency inversion is capable of producing a model which is good enough as a starting model.

The initial velocity/depth model from coherency inversion and CRS stack was used as input into prestack depth migration (PSDM). After the first run of PSDM, the by-products of PSDM, i.e. common reflection point (CRP) gathers were analysed for the correctness of the velocity model. In general, if the velocity model is correct then the depth images at a CRP should be independent of the source-receiver offset (Strok, 1992). A variation in the depth estimates versus offset leads to velocity adjustment of the model to eliminate "smiles" or "frowns" as a function of offset for the migrated CRP depth gathers. With the correct velocity/depth model the CRP gathers should be "flat", i.e. independent of offset. This approach is similar to normal moveout analysis of CMP data.

With the new velocity model section, a new run of PSDM was performed and the layer geometry for the corresponding layers was determined by picking new depth horizons from the migrated section. The horizon interpretation was based on the migrated section and constrained by surface structural geology section and the CRS stack sections. Figure 6 shows the flow chart used in estimating and upgrading the final

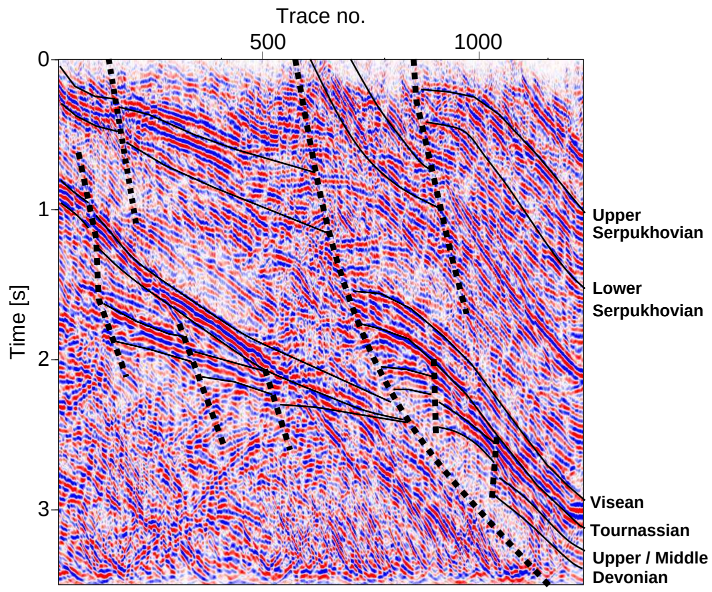

Figure 3: Interpreted time horizons on the migrated CRS image. This figure shows details of the basement involving thrust on the southern flank of the Foldbelt.

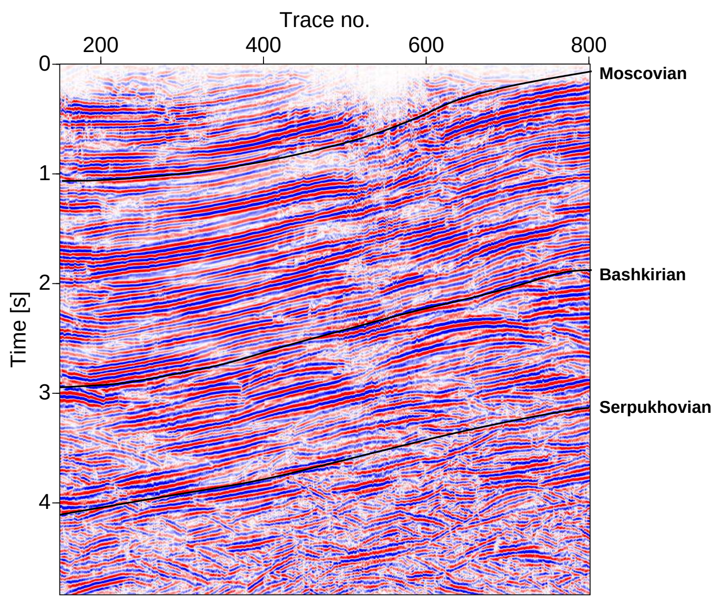

Figure 4: Time horizons on a CRS stack migrated section showing three distinct stratigraphic units.

velocity/depth model. The process of horizon interpretation was crucial because wrong interpretation of horizon geometry could lead to a wrong depth model. Along the survey line there were no geologic informations from well log data. Therefore, only surface structural geologic information was used to constrain the seismic interpretation. Layer velocity updating, re-migration and re-interpretation of layer geometry were repeated until the velocity/depth model and the depth migrated section were fairly consistent. Figure 9 shows the final velocity/depth model of the DOBREflection 2000 line. In the crystalline part of the model, we used a smooth gradient model $v(z) = v_o + az$, with the gradient, a, given as 0.038, and $v_o = 5.9\ km/s$ as the starting velocity from the surface. The depth model ranges from 0 - 21 km with velocities from 4.0 - 6.2 km/s. Figure 7a and 8b are two sections of the final depth migrated image. Generally, the depth sections show detailed resolution of the basin sediments. The sedimentary cover is expressed as well-defined package of reflectors. Figure 8b displays a fragment of the axial part of the section at the depth of about 20 km. This figure displays a listric shear zone which also appeared on the surface and extends through the crust. This process of adjusting the velocity model via CRP gathers is usually known as residual moveout correction. After flattening each CRP gathers, the events are stacked to give the final depth section. Note that before stacking the CRP gathers, we first convert the CRP gathers to time domain and applied other conventional processing techniques on the gathers such as mute and filter in order to improve the appearance of the final migrated section. For this dataset it was possible to stack different offset ranges to examine the possibility of undershooting.

Following the methodologies described above reveals that an integration of geology and new seismics techniques is an important strategy for the success of the results. A direct advantage with this flow is that it is easy to bring in a priori information about the model in the process. In this work we have used interpretational information from the migrated CRS stack images and from surface structural geology. This shows that PSDM can be regarded as both a processing and an interpretative tool. Because the process of migration velocity analysis was iterative and all the shot gathers had to be re-migrated each time, we used first arrival prestack depth migration (Geoltrain and Brac, 1993). Therefore, a finite difference eikonal solver

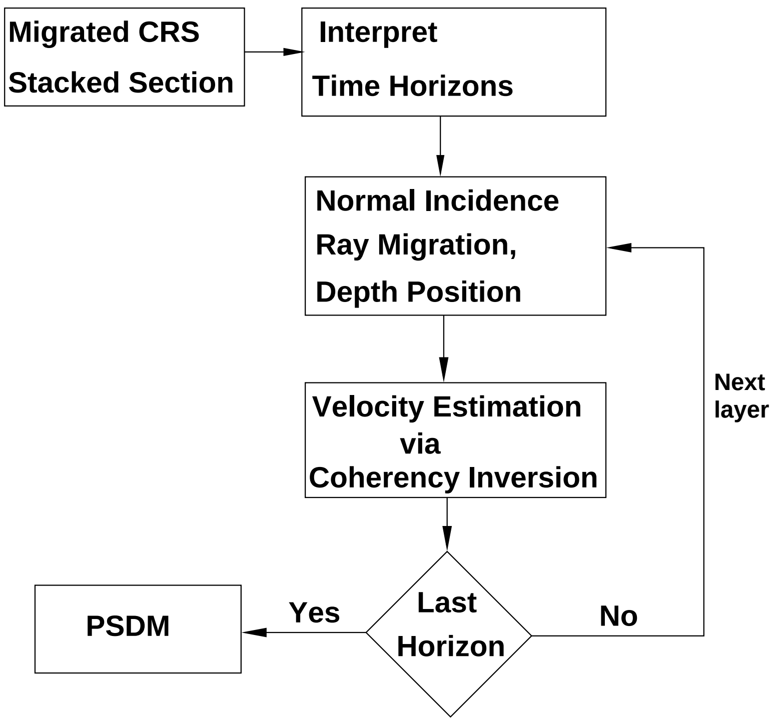

Figure 5: A scheme of the processing flow for estimating the initial interval velocity/depth model of the Donbas Foldbelt data.

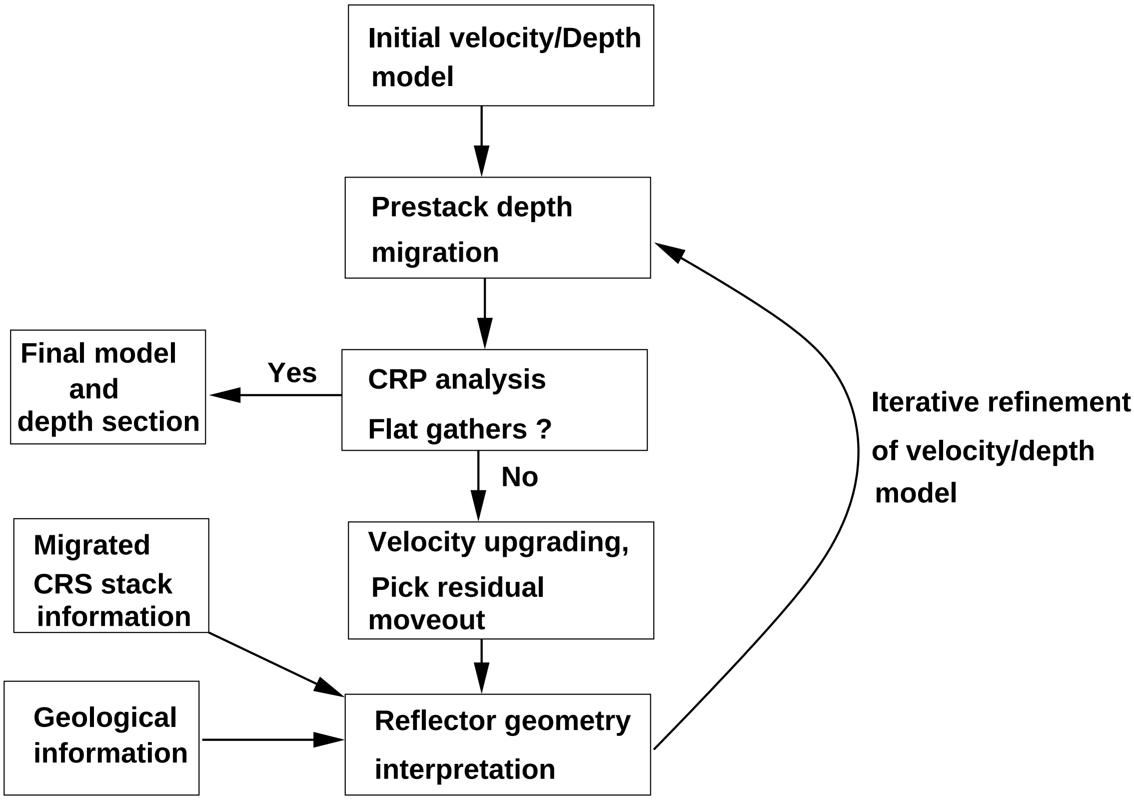

Figure 6: Iterative flow steps for obtaining the final velocity/depth structure. PSDM begins with an initial velocity/depth model from coherency inversion. If the CRP gathers are flat then the model was accurate. If the gathers are not flat then the model needs to be updated and the migration is repeated. Reflector geometry from migrated CRS stack images were used in areas where prestack depth migration produced poor results. Informations from structural geology were incorporated to interpret the depth migrated horizons after each re-migration.

was an appropriate tool for the generation of traveltimes. To further reduce the run time, a layer-by-layer model updating was applied. To obtain the final depth migrated section, we applied the maximum energy arrival prestack depth migration.

CONCLUSIONS

We have introduced a new strategy for imaging in complex areas on the a dataset of the DOBREflection 2000. We believe that the best way to construct an accurate model in such complex areas is by incorporating all information from model independent and model dependent methods. The model independent CRS stacking tool permitted the use of a macro-velocity model only during the PSDM phase. In estimating the velocity model we believe that velocity/depth model adjustment should be carried out in an interpretive setting with several tools when using PSDM on Foldbelt data.

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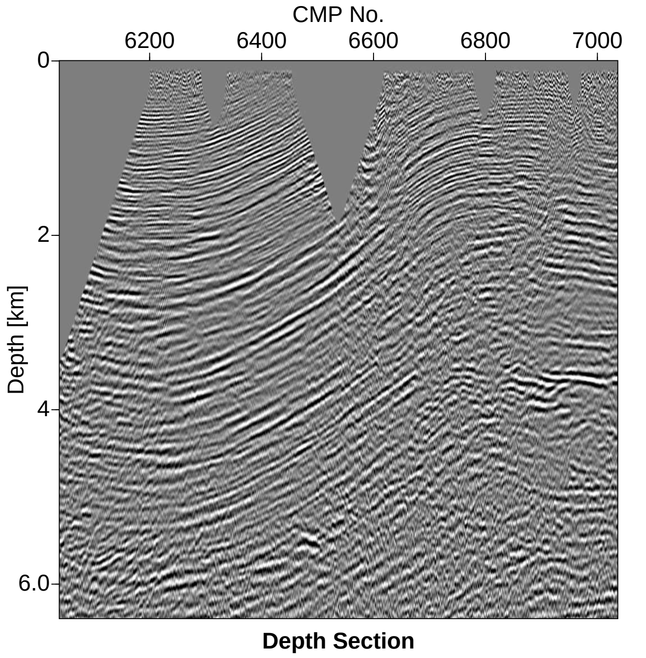

Figure 7: PSDM section using the final velocity/depth model shown in Figure 9. This figure shows the northern part of the basin with folded sedimentary packages at the depth of 6 km. The gaps of this section are due to lack of shot records.

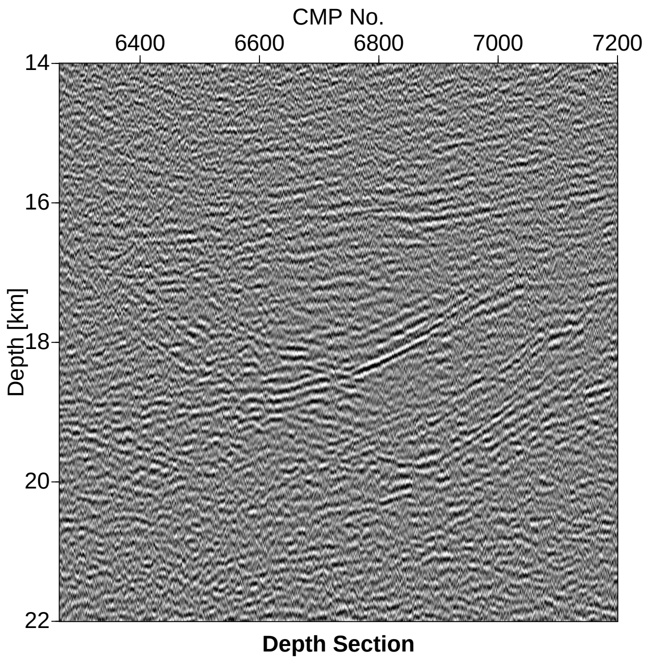

Figure 8: Part of the PSDM section using the final velocity/depth model shown in Figure 9. This figure shows the basement of the basin with two reflectors. The depth of the reflectors is between 19-20 km and the reflectors are separated by a listric shear zone which continues through the Moho.

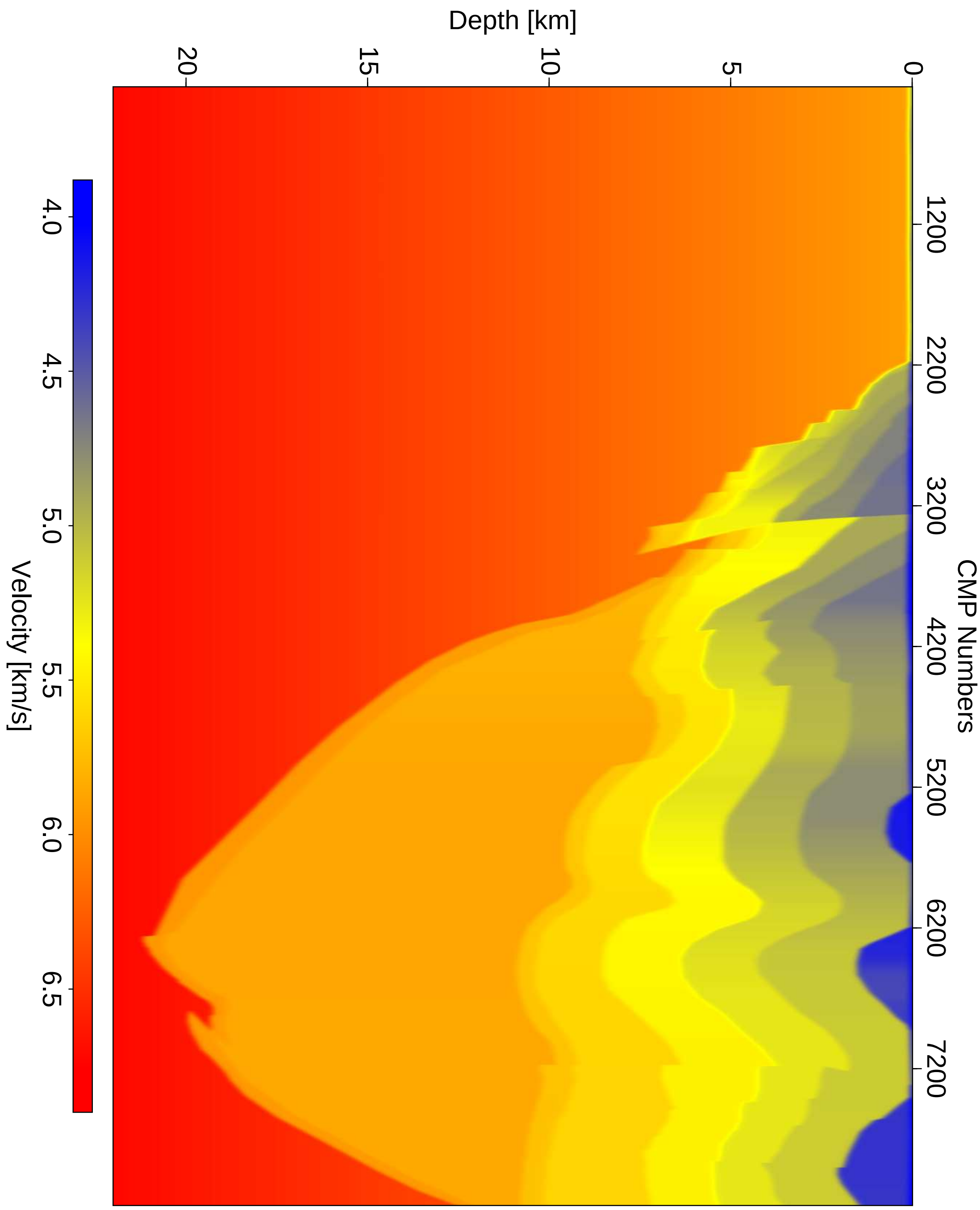

Figure 9: Interval velocity/depth section of the DOBREflection 2000 line. Within the sedimentary layers the velocity values ranges from 4.0-6.2 km/s.

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