Chapter 10

Dissertation Summary

10.1 Part I

The purpose of the first part of this dissertation was to develop a migration algorithm for converted waves, and a tomographic method for estimating an interval shear wave velocity model. The developed algorithm is based on the Kirchhoff formalism.

The elastic Kirchhoff integral and its implementation were discussed and summarised in Chapter 2. The derived migration integral was generalised for all types of multicomponent data. For practical reasons, multicomponent data are decomposed into their corresponding components (z, x, and y components), and the migration is performed separately for each component. Normally it is assumed that the decomposed wave components are free from other wave types. The migration result of each component shows particular characteristics of the subsurface. For example, PS data give the shear wave characteristics of the subsurface.

Chapter 2 also discussed the finite difference eikonal solver for computing seismic traveltimes, and the incorporation of the perturbation method into the traveltime algorithm. The perturbation method allows for a simultaneous migration of PS data with a given range of P- and S-wave velocity models. This simultaneous migration is important for iterative PS migration velocity analysis. The first arrival traveltimes computed by the FD method are accurate enough to perform a fast target oriented prestack depth migration.

In addition to the accuracy of the traveltime algorithms, the success of prestack depth migration strongly depends on the accuracy of the interval velocity model. Conventional one component migration velocity analysis works on the principle of flat CRP gathers, if the corresponding input migration velocity is correct. For PS data this is not always true. PS CRP gathers may be flat, even if the interval S-wave velocity model is incorrect. Therefore, if flatness of PS CRP gathers is the only criterium for velocity correctness, this may lead to wrong velocity interpretation. Chapter 3 described a new tomographic approach for updating interval S-wave velocities and v_p/v_s-ratios. The function to be minimised in the tomography were depth shifts between PS and PP CRP gathers. The depth shifts are converted to time differences, and the time differences are input into the tomographic inversion. The validity of the algorithm was tested on synthetic and field data in

Chapter 4.

The examples showed that the proposed method led to a correct S-wave velocity model in which both PS and PP depth gathers were tied in depth positions. Good reflection continuity and event character were observed on both PP and PS data sets, and reliable correlations could be made between the P- and S-wave data. The proposed tomographic method is stable because reflector depths are not updated. The depth positions are previously estimated from the PP data section. Note that the method is different from conventional reflection tomography because reflection events are picked after depth migration, i.e., in the stacked domain with improved S/N-ratio.

The following points can be concluded from this part of the thesis.

1. Prestack depth migration is the most accurate method for imaging of converted waves. Imaging in the depth domain reveals no lateral shift in the image position between PP and PS events as is usually observed in time domain processing.

2. If flatness of CRP gathers is the only criterium for estimating the correct PS migration velocities, then PS and PP depth positions from the same reflection horizon can be different.

3. The PS CRP gathers can be flat even if the migration S-wave velocity is incorrect.

4. A necessary and sufficient criterion for PS migration velocity analysis is to assure flatness and depth tie of PS and PP CRP gathers. If both PS and PP data correctly match then the derived interval P- and S-wave velocities can provide a direct measurement of physical properties of the rocks.

10.1.1 Future Work

The tomographic approach described in Chapter 3 is a very useful tool for 2D data. Its application to other complicated data sets and especially in a 3D data still has to be validated. Furthermore, in its present form, the algorithm does not consider anisotropic effects in the model. Anisotropy is always present in nature and can affect PS data more than PP data. Therefore, more research is needed to expand the algorithm to estimate anisotropic parameters through tomography.

The tomographic method in Chapter 3 assumes a previous knowledge of a PP velocity/depth model. However, the PP velocity/depth model can be inaccurate. In such a situation both P- and S-wave velocities have to be jointly updated. Therefore, research still has to be done for the case were both P- and S-wave velocities are incorrect. In this respect, the P-wave velocity model obtained from PP data can be used as an initial model for further updating during PS migration velocity analysis.

10.2 Part II

The second part of this work was devoted to integrating model-independent and model-dependent seismic imaging methods in a single workflow in order to construct a velocity/depth model and a depth migrated section of the Donbas Foldbelt data. The estimation of the model required the integration of the different methodologies and disciplines, each of which gave different information on the subsurface. The model-independent method involved the common reflection surface (CRS) stack method, which give a high quality zero-offset stacked section. The model-dependent method involved Kirchhoff prestack depth migration (PSDM). The integrated workflow for estimating the velocity/depth model was made up of the following:

- Generate a high quality unmigrated stacked section with the CRS method.
- Interpret the main time horizons on the CRS section.
- Using the time horizons, perform coherency inversion to generate an initial model.
- Perform iterative PSDM, starting with the initial model and interpret the migrated stacked section.

Before applying the CRS method to the field data, the algorithm was tested on a synthetic data generated from the Picrocol model (Chapter 6). The synthetic test showed that the CRS algorithm requires readjustment of some input parameters. These input parameters control the quality of the stacked section. The unmigrated CRS stacked section accurately represents a zero-offset image which is a requirement for accurate poststack imaging. Apart from the zero-offset stacked section, other attributes such as a high density stacking velocity section and the wavefield attribute sections are produced. The wavefield attributes are the angle of emergence of the hypothetical wavefronts at the surface, the radius of curvature, R_{NIP}, of the NIP-wavefront and the radius of curvature, R_N, of the N-wavefront. These additional sections can be further used for other inversion purposes to describe the subsurface model. For example the correct geometry of the reflector can be directly estimated from the R_N-section.

The application of the CRS method on the field data revealed improved image quality in areas which previously showed poor image quality on conventionally CMP stacked sections. Even though the CRS method was applied only to particular key zones of the Donbas profile, it could equally be applied to image the complete section. Time horizons on the migrated CRS stacked section were easily interpreted due to the high image quality. Because imaging with CRS does not depend upon the stacking velocity model, errors due to a wrong stacking velocity model were avoided. Furthermore, any error due to the processors mal-picking of prestack reflection events during stacking velocity analysis was also avoided. This implies that all the reflection events in the stacked section were purely data-driven. These events were interpreted and given as input into the model-dependent part of the imaging.

The model-dependent imaging begins with the generation of an initial velocity/depth model through coherency inversion. For this purpose, time horizons from the migrated CRS sections are used as input into coherency inversion. In complex geology, like the Donbas Foldbelt area, I suggest to pick time horizons on poststack migrated sections. This is because picking of time horizons on unmigrated stacked sections, including the complete spread of triplications, is not at all trivial. Note that the accuracy of the coherency inversion result depends on the correctness of the time picks. The generated initial model from the coherency inversion is used for PSDM.

The initial model from CRS stacking and coherency inversion is iteratively updated and re-used in PSDM until a consistency is achieved between the input model and the depth migrated section. The criteria for the correctness of the velocity model are based on flatness of migrated CRP gathers along the profile. For the Donbas Foldbelt data, CRP gathers were analysed every 200 m. This was dense enough to resolve lateral velocity variations within the layers. Structural geological information was important for interpreting the depth migrated section. After each migration iteration, the depth horizons were re-interpreted to give a new depth model. In this way, additional information from geology and CRS images were easily incorporated into the model updating flow. Therefore, an understanding of the geology of the area was required for accurate interpretation.

This research work has demonstrated that incorporating information from model-independent imaging, model-dependent imaging, and surface structural geology can lead to an accurate estimation of structural velocity/depth models in complex environments.

10.2.1 Future Work

The model-independent imaging was applied only to certain key zones which demonstrated the extent of the basin inversion. With new computer capacity and performance, future work can involve the application of the method to the whole section. This might lead to further imaging of other reflectors which are missing, maybe due to wrong stacking velocities.

Likewise, a future research work is required to investigate the use of the CRS stack wavefield attributes for further inversions. For example, the wavefield attribute sections can be used for inverting for interval velocity, accurate estimation of reflector curvature, estimation of statics and suppression of multiples. The high density, high resolution CRS stacking velocity section can be converted to interval velocities via Dix's formula. This velocity can then be used for poststack depth migration of the CRS stacked sections and PSDM can be used to verify the correctness and upgrading of the interval velocity model.

Another research work will be to develop a PSDM algorithm which take into consideration the true topography of the survey area. In this way I presume that the quality of the depth migrated section can be further improved.