Chapter 5

Summary and outlook

From a number of deep seismic surveys and borehole measurements it is known that heterogeneities of various sizes and different magnitude of velocity fluctuation are distributed within the subsurface. The amplitude and phase fluctuations due to scattering of the wave field severely influence the reflectivity and the coherency of reflections. Thereby, the reflections from the heterogeneous medium itself as well as from structures below are affected.

In this thesis prestack depth migrated images of synthetic and real data sets were analysed to provide an improved understanding of reflection images from complex media. Thereby, the image distortion due to the heterogeneous layer, the reflection images containing narrow-frequency-bands (RIS) and the influence of errors in the migration velocity on the reflectors were investigated in three numerical experiments. The obtained results were compared with the results from to real data case studies. Three deep reflection data sets from the South American Andes (ANCORP, PRECORP, NVR-SPOC) were processed using Kirchhoff prestack depth migration. The ANCORP data set was migrated using three different velocity models. Furthermore, the ANCORP and the NVR-SPOC data were analysed using the RIS method. The most important results are summarized in the following.

5.1 Summary

5.1.1 Numerical modelling

The numerical modelling experiments were carried out to investigate the influence of scattering in the heterogeneous layer on seismic images. The synthetic depth sections were calculated using finite difference modelling and Kirchhoff depth migration. The velocity models consisted of a heterogeneous layer located above a deep reflector. The correlation lengths and the magnitude of the velocity fluctuations in the layer were varied such that weak, intermediate and strong scattering phenomena were observed.

In the first experiment the influence of scattering on the reflectivity and on the coherency of the reflector was studied. The average reflectivity in the heterogeneous layer and along the deep reflector was analysed. The results showed that for weak velocity fluctuations (1 %) the observed reflectivity in the heterogeneous layer was similarly weak for all correlation lengths. The deep reflector below appeared strong and coherent for all correlation lengths. For strong velocity fluctuations the reflectivity in the heterogeneous layer increased. However, the reflectivity was dependent on the ratio between the wavelength and the correlation length. It was stronger for correlation lengths larger than the dominant wavelength than for correlation lengths in the order of the wavelength. The reflectivity of the deep reflector decreased when the velocity fluctuations became strong. A comparison of the reflectivity for the same standard deviation but different correlation lengths showed that the reflectivity is stronger for correlation lengths larger than the wavelength. The deep reflector nearly disappeared for 20 % standard deviation in all models. The results show that the amount of scattered energy in the heterogeneous layer is not only dependent on the magnitude of the velocity fluctuation, but also on the size of the wavelength relative to the correlation length. The apparent reflectivity can be significantly decreased by scattering loss when the correlation length and the wavelength are of similar size. Deep reflectors cannot be imaged and will not be detected. In real data application this might lead to structural misinterpretation of reflection images and thus should be considered.

A comparison of the results with the ANCORP image suggested that strong scattering in heterogeneous layers might cause the abrupt change in reflectivity of the Nazca reflector at depths larger than 80 km as well as the lack of deeper reflections in the eastern part of the profile. It is assumed that the QBBS and the Altiplano reflectors represent such heterogeneous layers. The correlation lengths of the heterogeneities in the QBBS are estimated to be few kilometers, and in the Altiplano region a few hundred meters.

In the second experiment the RIS method was applied to the synthetic data. The synthetic depth sections were low-pass and band-pass filtered in different frequency ranges. The migrated images were compared to the image containing the entire frequency band. The deep reflector appeared incoherent and disrupted in the broadband image. The analysis of the low-pass filtered depth sections showed that continuous suppression of high frequencies continuously decreased the image fluctuations along the deep reflector. The coherency of the reflector increased continuously towards lower frequency contents. Finally, in the low-frequency image the reflector appeared coherent and plane, reproducing the real reflector shape. From the analysis of the band-pass filtered images it was revealed that mainly the high-frequency components were affected by coherency loss due to scattering. For lower frequencies the image fluctuations along the reflector were small.

In the last numerical experiment it was studied how velocity errors affect the shape and the coherency of a reflector located below a heterogeneous layer. Migrated images of the same data, but using different velocities were calculated and compared. The results showed that mainly the depth of the reflector image was affected. The coherency and the shape were not affected. The reflector was shifted linearly to smaller depth when using slower migration velocity and shifted into larger depth when using faster velocity. The shape of the reflector was not distorted by using wrong migration velocities.

5.1.2 Real data application

Central Andes

The ANCORP and the PRECORP data were prestack depth migrated. The migration provided a detailed structural image of the subduction zone. Both depth sections show a bright spot in the fore-arc: the Quebrada Blanca Bright Spot (QBBS) in the ANCORP section and the Calama Bright Spot (CBS) in the PRECORP section. The QBBS is located at depths between 15 - 40 km and shows a west and north dipping component. The CBS is located about 10 - 15 km closer to the surface and shows a west dipping component as well. Both bright spots appear delimited by the Precordilleran Fault System, but with changes in spatial relationship. Regarding the north dipping component of the QBBS and the upward shift of the CBS it is suggested that both bright spots might be somehow connected, or at least were caused by the same geological structure or processes. In the ANCORP image the Nazca reflector is visible over a distance of about 110 km in E-W direction. The compiled image of the depth section with local earthquake data shows a good spatial correlation between the hypocenter locations and the upper boundary of the oceanic crust at the beginning of the profile. At greater depths an offset between the hypocenters and the Nazca reflector is visible. A slightly smaller offset is observed in the PRECORP image between the Nazca reflector and the local hypocenters.

To study whether the observed offset is a result of using wrong migration velocities or whether it is related to the subsurface structure, the ANCORP data were recalculated using two alternative velocity models from tomographic inversion. The tomography velocity models differed significantly from each other and from the refraction data model. The comparison of the three depth sections showed that the refraction model provides an accurate image of the reflections from the oceanic crust in the beginning of the profile as well as of the deeper Nazca reflector. In both other images either the reflections from the boundaries of the oceanic crust are not properly imaged in depth or the Nazca reflector appears distorted and diffuse. The compilation of the depth sections with the hypocenters shows that the apparent offset remains in both recalculated images. It is concluded that the offset is independent from the used migration velocity model, but related to the subsurface structure.

Additional structural details of the Nazca reflector were obtained by the application of the RIS method to the ANCORP data. The ANCORP data were band-pass filtered in three frequency ranges and migrated. In all of the narrow-band-frequency images distinct reflections from the top and bottom of the oceanic crust are observed along the first 110 km. In the middle of the profile the high-frequency image (15 - 20 Hz) reveals thin east dipping reflections that were not visible in the broadband depth image. These reflections are located near the lower boundary of the Nazca reflector and are interpreted as the top of the oceanic crust. The depths of these reflections match well with the linear continuation of the oceanic crust into larger depths. The high-frequency image also shows thin horizontal reflections at a depth of 80 km, located at the upper boundary of the Nazca reflector. These reflections are interpreted as the top of the reflective continental mantle wedge. An improved interpretation of the PRECORP section is presented. The horizontal reflections observed at a depth of 80 km are interpreted as the highly reflective continental mantle wedge. The thin east dipping reflectors at depths larger than 80 km are interpreted as the subducting oceanic crust. The continuation of the top of the oceanic crust in larger depths derived from the reflection image indicates that the local seismicity is limited to the oceanic crust and in the upper mantle as well.

The internal structure of the Nazca reflector could be resolved by the presented images, which was not observed in the poststack image. Thus, new insights are provided improving the knowledge and the understanding of the deeper subduction zone and the processes therein.

Southern Andes

The SPOC-NVR data set from the Southern Andes was prestack depth migrated and provided a 100 km wide and 40 km deep image. Mainly reflections from the permotriassic accretionary wedge are observed. Besides mainly east dipping reflections a band of horizontal reflections appears at a depth around 23 km in the image. This band shows a good correlation with the wide-angle reflector of the boundary between the upper and the lower continental crust. Reflections marking the top and the bottom of the oceanic crust were obtained by enhanced amplitude stacking and trace normalisation. These reflections correlate well with reflectors observed in the wide-angle data. The RIS method was applied to the data. Additional details of the structures within the continental crust were not obtained. However, in the low-frequency image a strong reflection from the oceanic Moho at depths between 35 - 40 km was observed. It is assumed that the NVR data are very sensitive to the stacking scheme and to the amplitude enhancement processing due to its low coverage and the low signal-to-noise ratio.

5.2 Outlook

The RIS method was applied to synthetic and real data sets and provided first meaningful results. The focus of the application was mainly set on the analysis of the reflector image, i.e. coherency and apparent reflectivity, as well as on the uncovering of reflectors that were masked in the broadband images. The application to real data sets showed that this method is able to visualise certain details that improve the interpretation of seismic reflection images. The analysis of the synthetic RIS depth sections showed that the coherency and the reflectivity of reflectors significantly differ in narrow-frequency bands. However, it was not revealed how spatial parameters of the heterogeneities are obtained directly from RIS images. The quantitative relation between the apparent reflectivity in the heterogeneous layer and the correlation lengths in dependence on the frequency has to be investigated in detail. Furthermore, the numerical studies showed that the observed reflectivity in a heterogeneous layer is not only dependent on the magnitude of velocity fluctuations, but also on the correlation lengths of the heterogeneities. However, the relationship between the apparent reflectivity and the correlation length was not exhaustingly studied. For example the influence of the vertical correlation length on the reflectivity was not taken into account. Thus, further numerical modelling studies are still necessary to gain a more profound understanding of the effects of scattering on seismic images as well as of the RIS method and its benefits.