IMAGING OF CRUSTAL REFLECTION DATA WITH THE COMMON REFLECTION SURFACE (CRS) STACK METHOD - NEW INSIGHT INTO THE CRUSTAL STRUCTURE OF NORTHERN GERMANY

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ABSTRACT

In this paper we present new seismic images of the North German Basin and its crustal features that resulted from reprocessing of industrial reflection data sets using the CRS stack method. The data were acquired and already processed in the 80ies with the main focus on the sedimentary fill of the basin. The processing was based on conventional CMP stacking. The focus of the reprocessing was moved to lower crustal structures in order to investigate the influence of old deep rooted processes on the evolution of the Central European Basin System (CEBS). In the reprocessed sections the image quality of the lower and middle crust and the visibility of the Moho could be significantly improved. The present day Moho appears as a flat boundary lacking the typical features of basin formation and graben developments.

INTRODUCTION

An extensive database was gathered by the Oil- and Gas Industry in the 70ies and 80ies to explore the North German Basin for hydro carbons. This data base also included reflection seismic profiles recorded up to 15 s TWT which where recently released to the priority program SPP 1135 *Dynamics of the Sedimentary Systems* of the Deutsche Forschungsgemeinschaft. Th processing of the reflection data by the industry in the 80ies was tuned to image the basin sediments down to the Zechstein using basically standard CMP processing. The potential of the data to image the crystalline crust was never optimized and only marginally exploited although structures in the lower crust and partly also some Moho reflections were already visible in the CMP stacked data. The CRS stack method (Müller et al., 1998; Mann, 2002) has already been successfully applied to reflection data from sedimentary basins (Trappe et al., 2001; Menyoli and Hübscher, 2004), but yet it has not been used to investigate the crystalline crust and deeper structures. With the focus on deeper crustal structures three seismic reflection lines of this data base have been reprocessed using the CRS stack method.

STUDY AREA AND DATA SETS

The reprocessed seismic reflection lines 7405, 8106 and 8401 were located in the area of the Glückstadt Graben which is one of the deepest post-Permian structures in the Central European Basin (Fig. 1). The north-south heading reflection line 7405 was about 130 km long. Line 8401 was shot as a western prolongation of line 8106. The total length of these east-west heading lines were about 300 km. The total recording time of the data was 13 s to 15 s TWT. The geophone spacing was about 100 m for line 7401 and 20 m for line 8106-8401. The number of recording channels was 48 and 120 for line 7401 and 8106-8401, respectively. The maximum offset was 4.8 km for all profiles. The acquisition geometry was irregular in

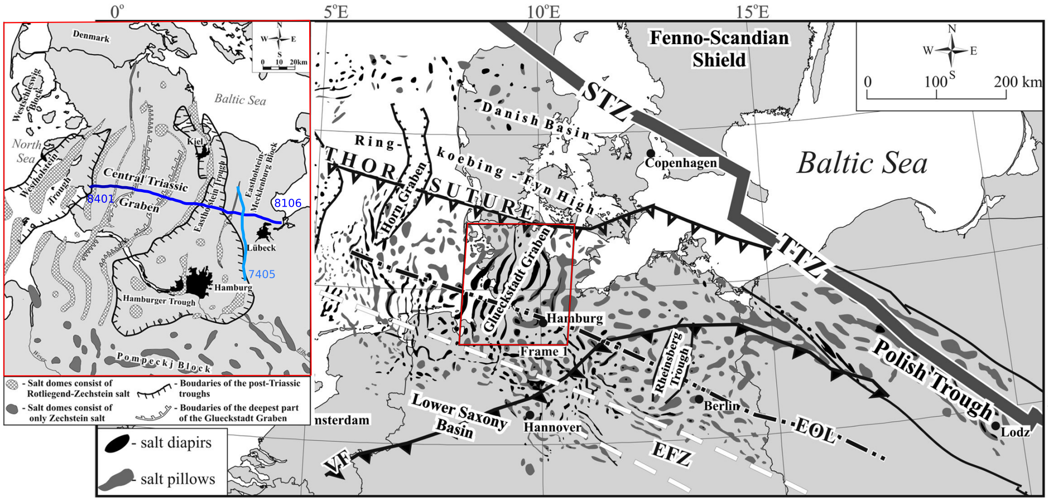


Figure 1: Tectonic map of the Central European Basin with the major crustal structures and fault zones (modified after Maystrenko et al. (2005)). The reprocessed reflection lines 7405, and 8106-8401 are located in the area of the Glückstadt Graben (see inset).

some parts along the lines. This resulted partially in a CMP fold less then ten. The mean CMP fold of the data sets ranged between 15 and 20. The maximum fold was about 30. In general the CMP fold of this data is very low compared to contemporary acquisitions. The low fold of the data made the application of the CRS method particularly interesting since much more traces are included in the CRS stacked sections and the signal-to-noise can be significantly increased.

DATA PROCESSING

Preprocessing

The preprocessing of the data sets basically consisted of setting up the acquisition geometry, trace editing, i.e. removal of dead traces, noise elimination, muting and frequency filtering. The applied static corrections were available either on paper (line 7405) or as electronic documents (line 8106-8401). Also, residual statics were applied using the FOCUS tools. An automatic gain control was applied to the data prior to the CRS stack.

Only paper copies of the former processed CMP sections were available. For direct comparison the CMP stacked sections were recalculated using the FOCUS tool. The stacking velocities were taken from the paper copies of the final stacks provided by the industry. Partially additional stacking velocity analyses at some CMP locations were added for better resolution and imaging.

CRS stack

After preprocessing the CRS stack method (Müller et al., 1998; Mann, 2002) was applied to the data. To obtain an estimation for the optimal aperture sizes of the stacking operator the approximate size of the first projected Fresnel zone FZ at different reflector depths z were calculated using the following formula (Hertweck et al., 2003):

$$FZ = \frac{\sqrt{\frac{vzT}{2\cos\Theta_m} + (\frac{vT}{4})^2}}{\cos\Theta_m} \tag{1}$$

with v the medium velocity, T the dominant frequency of the signal and Θ_m the maximum dip angle. In the data sets the dominant frequency was about 25 Hz and the maximum dip angle was set to 60°.

Based on these values the parameters defining the size of the CRS stacking operators were modified in each calculation to optimize the images at the specified targets.

THE RESULTS

Fig. 2(a) shows the CMP stack of line 7405 (old CMP processing) and Fig. 2(b) displays the corresponding section after reprocessing with the CRS method. Fig. 3 shows line 8106 after classical CMP processing. The CRS stack of line 8106 is shown in Fig. 4. Fig. 5(a) and Fig. 5(b) show the CMP and the CRS stack of line 8401, respectively. Zoomed areas of line 8401 are shown in Fig. 6.

The comparison between the CMP stack and the CRS stack shows that the CRS stack generally improved the image quality of the sedimentary cover in all sections. Particulary also, the images of the internal salt structure were improved. Especially, the visibility of reflections from the crystalline crust and from the Moho was enhanced. Generally, the signal-to-noise ratio was significantly increased. But also multiples and diffractions are enhanced in the CRS sections since we did not exclude certain sets of CRS parameters yet. Without a particular choice of CRS attributes the CRS stack enhances all coherent energy in the data. In the initial phase of the reprocessing we did not want to make a pre-mature decision which energy is useful or not. In the following the results will be described in detail.

Internal structure of salt plugs

An interesting feature of the CRS stacked section is visible in the sedimentary cover of the basin particularly the salt plugs in the area of the Glückstadt Graben (see Fig. 4 and Fig. 6). The resolution of the events could be improved compared to the CMP processing. The images display predominantly horizontal reflection events which show continuity not yet recognized in previous processing results (for comparison see zoomed sections in Fig. 6). These reflections may be interpreted as Keuper horizons which would point to a different internal structure of the salt plugs than previously thought of and currently applied (Maystrenko et al., 2005). This observation, however, needs further investigation by additional processing, particularly pre-stack depth migration after careful velocity analysis. Pre-stack depth migration is clearly superior to CMP and CRS stacking in areas of great geological complexity and strong lateral velocity variations like salt structures. For a high quality imaging with pre-stack depth migration, however, a very good velocity model is required. For the model building we use stereotomography and CRS tomography. The results will be published in the next WIT report.

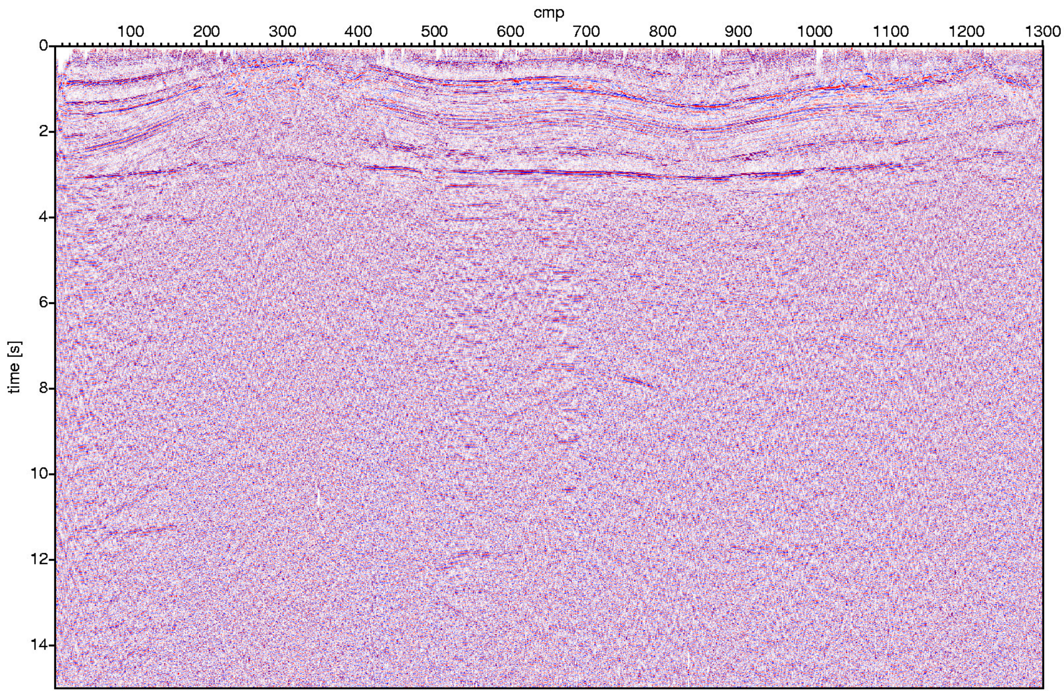
Mid crustal reflections

Some mid crustal reflections for CMP position 1550 and 1100 at about 8 s TWT are visible in the CRS stack of line 8106 (Fig. 4) which can be hardly identified in the corresponding CMP section (Fig. 3). In the present state of the processing we cannot conclude, whether these events correspond to the Conrad boundary, but it is obvious that the mid-crustal reflectivity clearly increases in the right (eastern) part of the section. This area was tectonically less active than the area in the western part of the profile. It will be interesting to note, whether this observation applies also to other reflection lines of the North German Basin. For the better evaluation of mid crustal reflections further processing on the multiples is required since the multiples mask mid crustal reflectors and reflectivity.

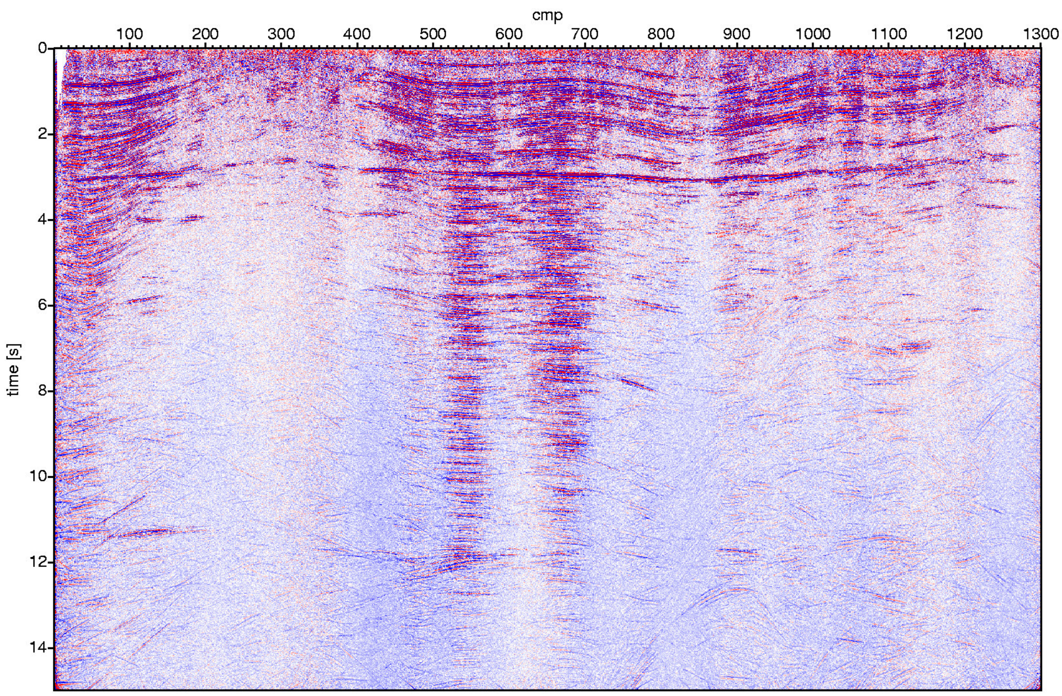
Deep crustal and subcrustal reflections

Reflections from the deeper crust were hardly visible in the CMP stacked sections. The results show that the CRS stack clearly improved the imaging of deeper crustal reflections. The characteristics of these reflections varies from sharp and continous in line 7405 (Fig. 2) to broad and diffuse reflection events in line 8106 (between CMP location 1000 and 1500, Fig. 3).

Especially, the image of the reflections from the deeper crust is of geological relevance. The Moho below the Glückstadt Graben at CMP 4300 of line 8106 (Fig. 4) was assumed to increase by about 4 km in this area (Bachmann and Grosse, 1989; Brink et al., 1990) forming a pronounced bump in its topography. The reflections corresponding to this interpretation are clearly visible as the strongest events at deeper parts of the crust below the graben proper at about 10 s TWT. However, a careful inspection of the event



(a) CMP stack section of line 7405. The sedimentary fill of the basin is adequatly imaged where as lower crustal reflections are hardly visible.



(b) CRS stack section of line 7405. Moho reflections are clearly visible. The image quality at this level is improved compared to the old processing shown in 2(a).

Figure 2: Comparison of CMP and CRS section of line 7405.

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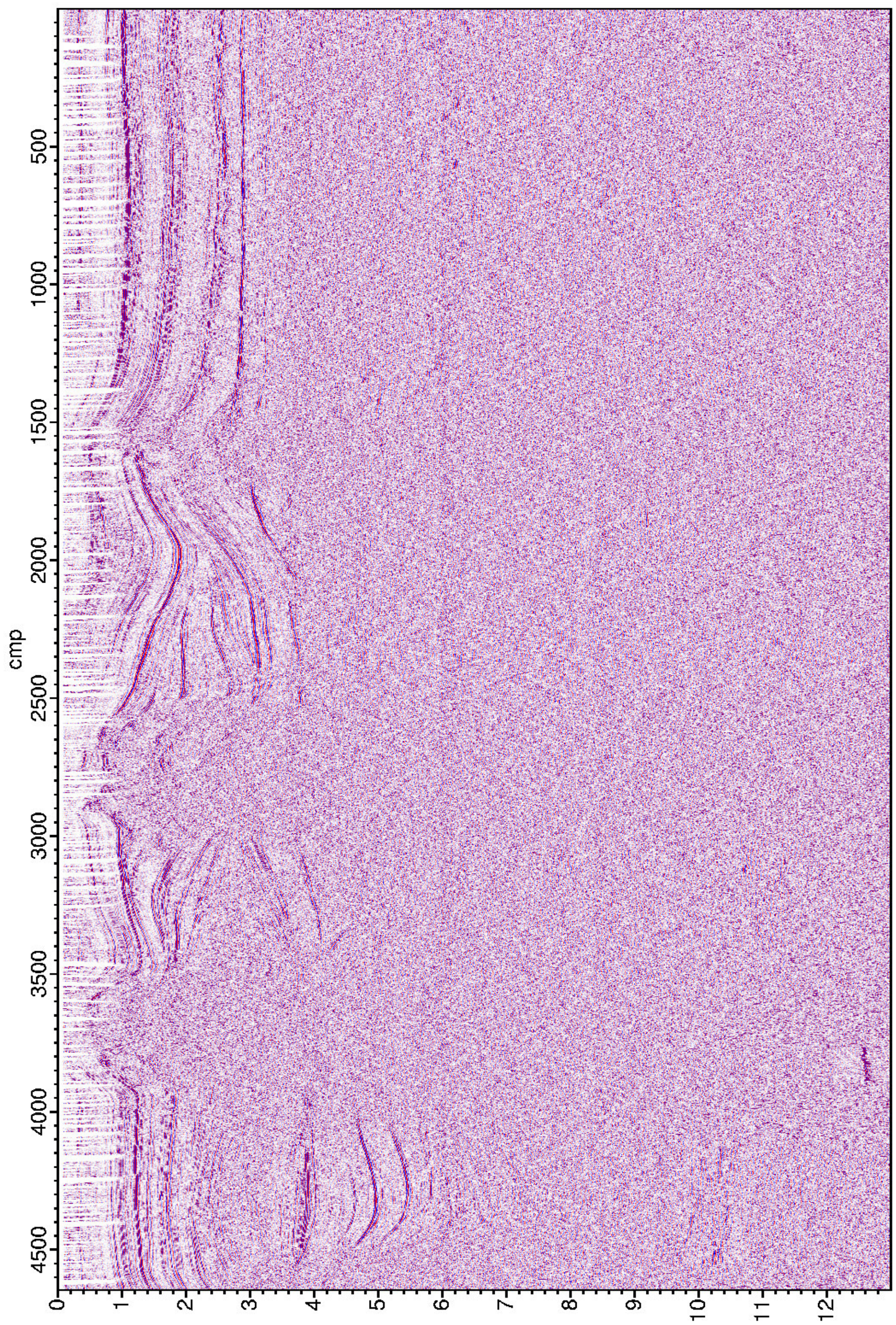


Figure 3: CMP stack section of line 8106.

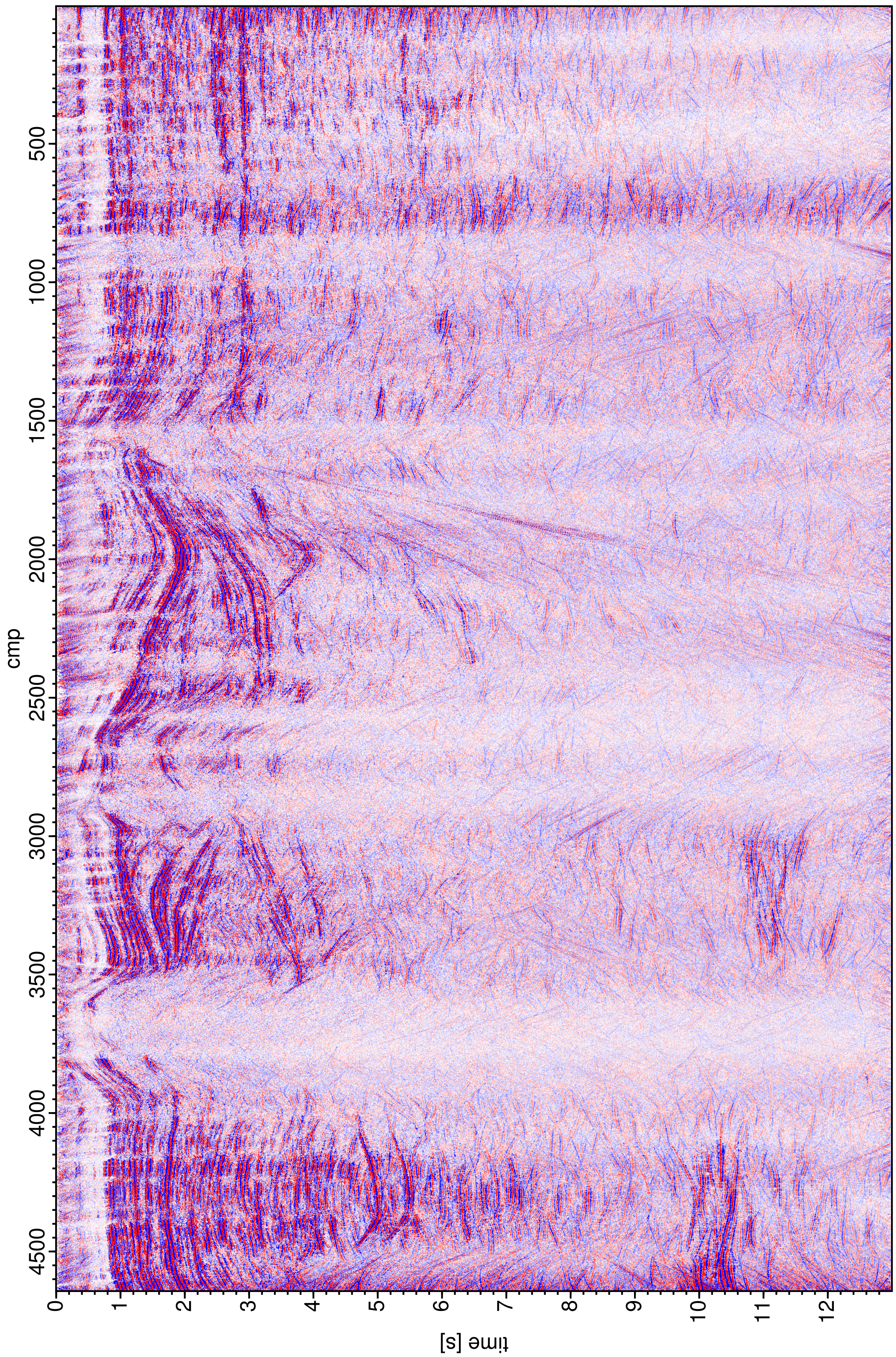
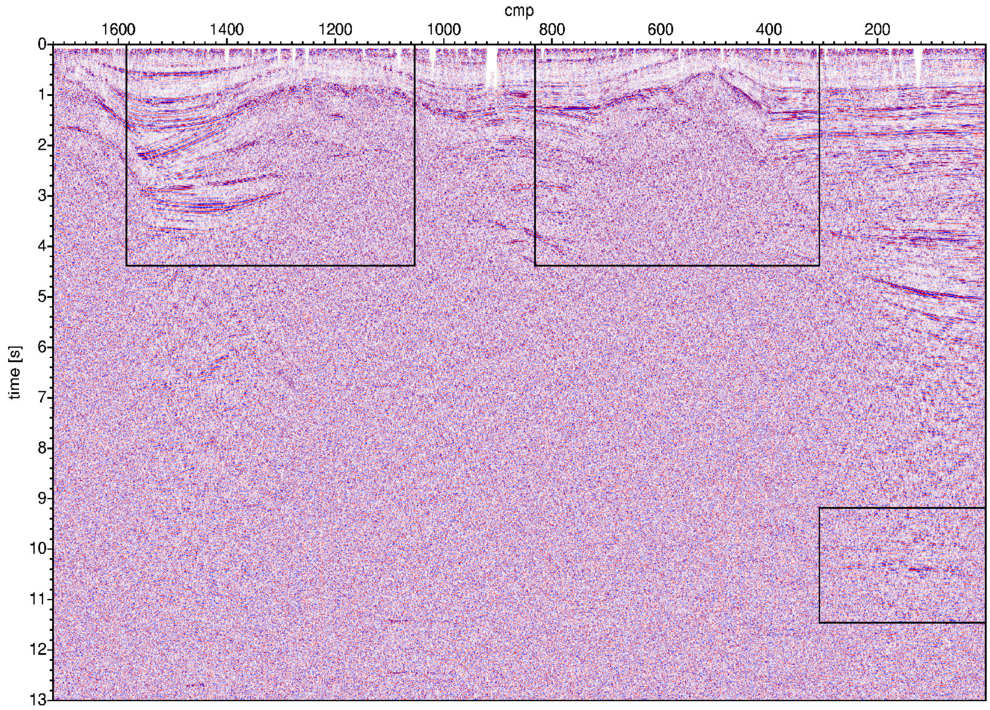
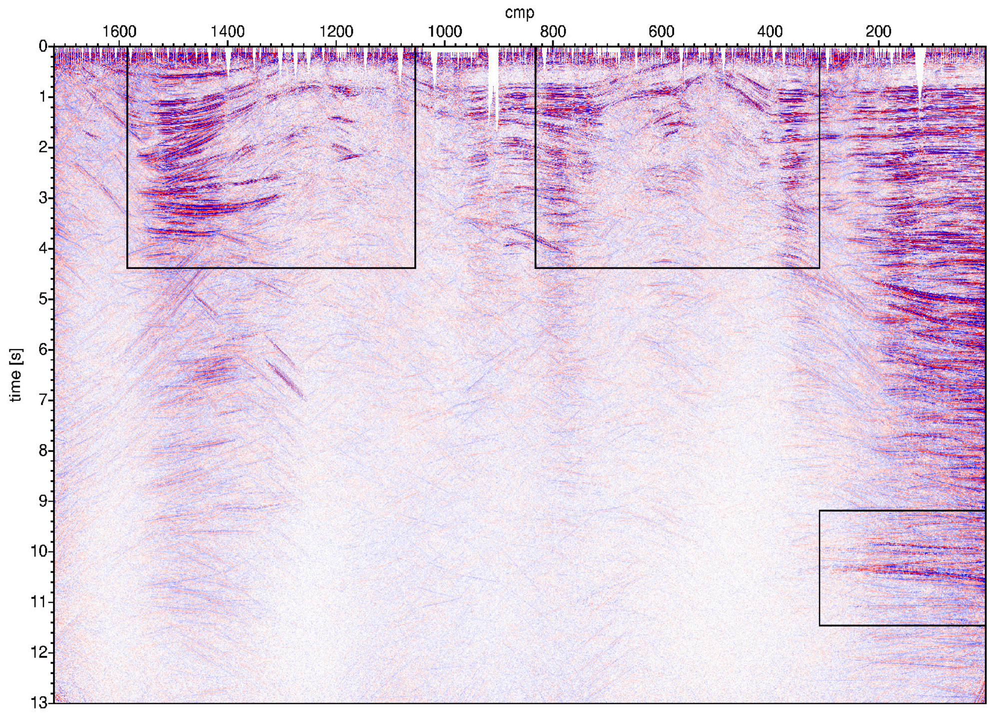


Figure 4: CRS stack section of line 8106.



(a) CMP stack section of line 8401.



(b) CRS stack section of line 8401 which represents the western extension of line 8106. The highlighted areas of salt plugs and crustal reflections are magnified in Fig. 6.

Figure 5: Comparison of CMP and CRS section of line 8401.

a)

b)

c)

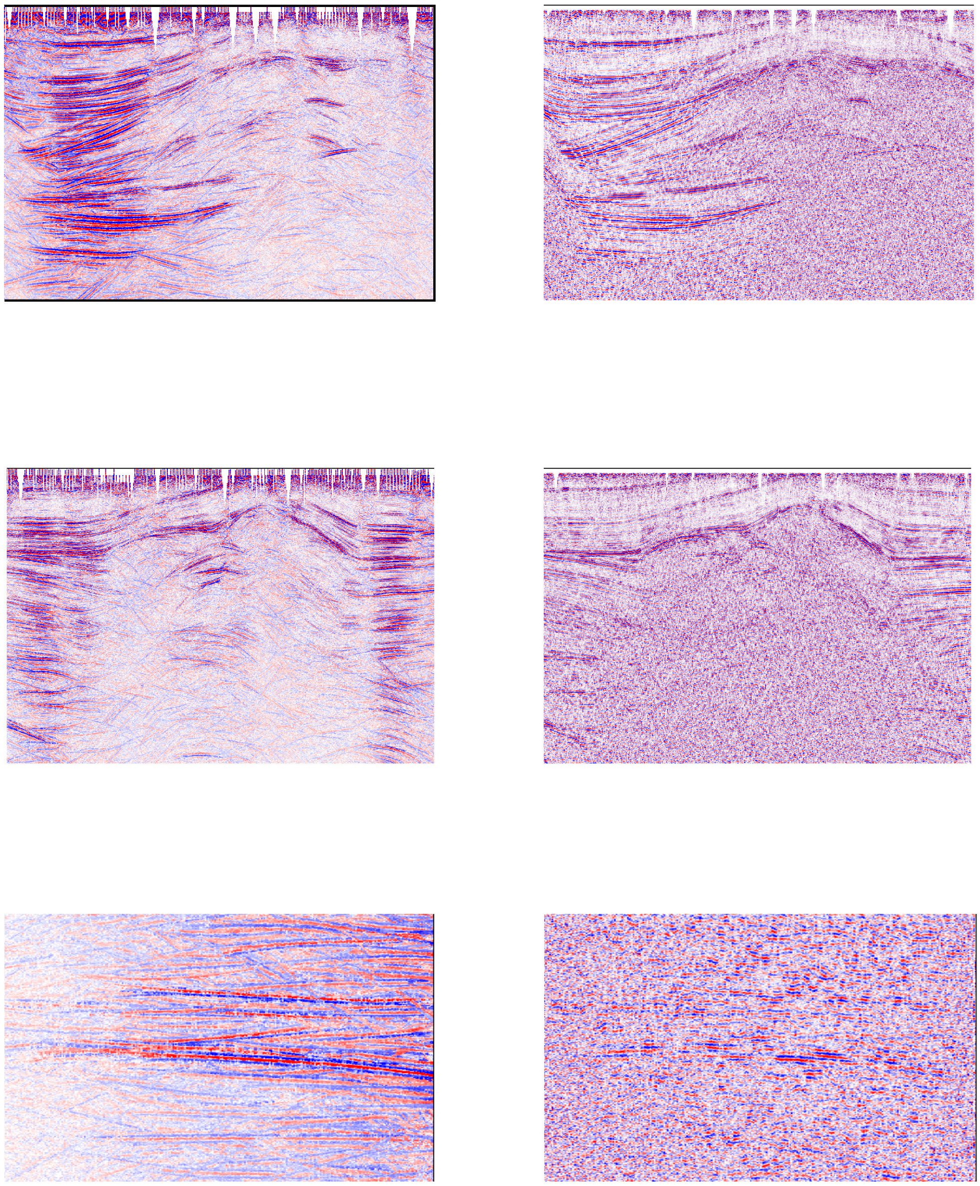


Figure 6: Right colum: Zoom of boxed areas in the CMP stack (Fig. 5(a)). Left Colum: Zoom of boxed areas in the CRS stack (Fig. 5(b)). Note the improved resolution within the salt plugs of the CRS processing compared to the CMP processing (a) and b). The deeper events could be interpreted as Keuper events. Also note the improved continuity of the crustal reflection events in the CRS section compared to the old processing (c).

characteristics reveals that these reflections are different from all other Moho reflections of this section (see e.g. Moho events at CMPs 3200, 2300 and 600-1800 at about 11-11.5 s TWT). The events in the area of the Glückstadt Graben area are much stronger in amplitude and also more continuous than the other events interpreted as Moho reflections in this section. Therefore, these events were not referred to as Moho reflections but as lower crustal events. Moreover, the weaker reflections at 11.5 s TWT exactly correspond in character to the events interpreted as Moho reflections elsewhere visible in this section.

This interpretation, however, results in a flat Moho at about 11.5 s TWT throughout the section and slightly increasing in TWT to the east. A flat Moho is in conflict with the currently supported extension model of the Glückstadt Graben. This area also corresponds to the location with maximum sedimentary thickness, i.e. the center of the basin where we would expect a Moho high. The flat Moho topography would be in good agreement with the observations of the DEKORP profiles (DEKORP-BASIN Research Group, 1999), located in the eastern part of the North German Basin, where also a flat Moho is observed (Bayer et al., 1999; Hoffmann and Brink, 2001). A similar observation is also reported by Maystrenko et al. (2003) for the reflection line in the Dniepr-Donets basin, Ukraine. There, also a flat Moho was observed in the basin center. A flat Moho in the area of the Glückstadt Graben combined with lower crustal heterogeneity will influence the gravity modeling as well as the Finite Element (FE) stress modeling in this area (Kaiser et al., 2005; Reicherter et al., 2005). This directly leads to the question, what the reflection Moho really represents (see, e.g. Mooney and Brocher (1987)). With respect to the geodynamic model it is important to keep in mind that we image the PRESENT DAY Moho and it remains an open question to what extend the present day Moho reflects the deeply rooted crustal processes which are responsible for basin formation which was initialized severl hundret million years ago. It is quite likely that the topography and depth of the present day Moho is overestimated with respect to the set up of geodynamical models.

The causes for the lower crustal reflector below the Glückstadt Graben are not yet resolved. However, recent gravity modeling by Bayer et al. (2005) reveals that a high density body in the lower crust is required to fit the observations. The location of the body coincides with the lower crustal layer found above the Moho in the Glückstadt Graben area. A detailed velocity analysis of the observed diffractions will hopefully provide interval velocities for this area to better characterize this local heterogeneity which could be a result of a metamorphic process. Prior to further interpretation attempts additional investigations are certainly necessary.

CONCLUSIONS

Although the CRS stack method suffered in areas with highly irregular acquisition geometry and extreme low fold (lower than 10) the reprocessing improved the seismic images considerably. Especially, the visibility of crustal structures and of the Moho events were enhanced. Also, the resolution of the internal structure of salt bodies could be improved. A first interpretation of the new images implies a flat Moho throughout the Glückstadt Graben area, which stands in contradiction to previous results and geological models. However, further processing such as velocity model inversion and pre-stack depth migration is still necessary in order to comfirm the new interpretations. Furthermore, as the CRS stack method enhances all coherent energy present in the data diffractions and multiples were enhanced as well. Suppressing of the latter events, which masque or even distort primary energy of deeper reflections, will be an important subject for additional data processing.

The CRS stack method provides a promising tool for processing of not only subsurface structures, but also for imaging of crustal and subcrustal features.

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