OPTAC (OPTimized ACquisition) Research Project – Are we acquiring redundant data?

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Summary

3D seismic acquisition is the most costly and time-consuming step in the exploration phase of a deep geothermal project. On the other hand, it is the only way to come up with a detailed assessment of the subsurface structural setting. The question therefore is how to reduce acquisition effort without losing quality of the seismic images. The research project OPTAC (OPTimized ACquisition) was designed to address such questions based on Innovative Energie für Pullach GmbH's 3D seismic dataset "Pullach". It is a typical 3D seismic dataset from the Molasse basin, an area with already well-established geothermal industry. The dataset was ideal for the purpose of the study as it was acquired in 2018 in a modern way with nodal receivers and single vibrators utilizing the technique of a simultaneous random sweep. It is therefore very comparable to recent acquisition designs. Different subsampling scenarios were created, and results were compared based on horizon slices and sections. Also, AVO gradient response was computed from pre-stack gathers. All data was compared based on standard input as well as Common Reflection Surface (CRS) processed data. Results show that for this particular dataset less fold would have led to a comparable result, especially if CRS technology was applied during processing. The results of the study could have a significant impact on geothermal acquisition design which is under pressure of economic aspects. This research was supported by the German Federal Ministry of Economic Affairs and Energy on the basis of a decision by the German Bundestag.

1 Introduction

Uncertainty or complete lack of knowledge about the subsurface structure is still the biggest risk in geothermal exploration. 3D seismic data is usually the key to addressing such risks. Areal subsurface illumination can only be achieved by 3D seismic data whereas 2D seismic gives a decent overview but cannot address lateral variations in rock properties or subtle geological features which vary laterally in thickness or extent.

Seismic waves are recorded with geophones which used to be connected by cable systems in the past. Those receivers have been transformed into independent nodes in the past years which are not limited by a cable connection anymore and can operate completely independently for a certain time window. Such technology allows for more flexibility in acquisition design and an increased number of receivers on the ground. However, we see a steep increase in receiver density and fold of coverage of newly acquired seismic data in the past years, too. The question arises whether such increase is technically required or simply done because nodes make things possible that had not been possible before.

The OPTAC (OPTimized ACquisiton) research project supported by the German Federal Ministry for Economic Affairs and Energy based on a decision by the German Bundestag was designed to address such questions. The basic idea of the project is a subsampling study of a given 3D seismic dataset. "Pullach 3D" of Innovative Energie für Pullach GmbH (IEP GmbH) was chosen as test dataset because it was acquired in a slightly oversampled way in shot domain with three shot positions per two

receiver positions. It was acquired in 2018 by CGG using single vibrators featuring CGG's Simultaneous Random Sweep technology. Table 1 shows the basic acquisition parameters of the 3D seismic survey.

Table 1: Basic acquisition parameters of Pullach 3D seismic dataset

Acquisition geometry	3D, orthogonal
Size	103 km²
Number of shot points	9700
Shot point distance	17.67 m
Shot line distance	424 m
Number of receiver points	9017
Receiver point distance	26.5 m
Receiver line distance	424 m
Receiver patch (max.)	16 lines x 256 receivers
Max. receivers per shot point	4096
Native bin size / nominal fold	8.84 m x 13.25 m / 64
Processing bin size (DMT processing 2018)	15 m x 15 m

The relatively small shot point distance of 17.67 m of the dataset is comparable to many of the more recent acquisition designs which often propose less than 20 m spacing. Vintage 3D seismic data was usually acquired with point spacings of 50 m, i.e. by far less dense.

Initial seismic data processing was carried out by DMT Petrologic GmbH & Co. KG (DMT) in 2019 on a 15 m bin size increasing the nominal fold of 64 to about 120. The input data to this research project were the pre-migration data delivered by DMT which had a sampling rate of 2 ms and a trace length of 5000 ms. The trace length was truncated at 3000 ms since depth of the target horizon was about 1600 ms to 2000 ms TWT. All other data was kept identical to allow for proper comparability of results. The complete set of input data was

1. CMP gather after deconvolution; SEG-Y format
2. Raw stack, post-stack processing, no scaling, zerophase; SEG-Y format
3. Raw pre-stack time migrated stack, no post-stack processing, no scaling, zerophase; SEG-Y format
4. RMS stacking velocity model referenced to floating datum elevation; SEG-Y format
5. Pre-stack time migration velocity model referenced to final datum elevation; SEG-Y format
6. Zero-phase operator; SEG-Y format.

2 Work Program

The work program of the project was designed to address the question of whether comparable results would have been achieved with a subsampled dataset. For that purpose, certain shots and/or receiver stations were dropped from the input data. In addition, the Common Reflection Surface (CRS) processing technology was applied to the same subsampled data for comparison. This software-based method for wavefield reconstruction was developed by Prof. Hubral at the University of Karlsruhe in the late 90s for a highly detailed description of the seismic wavefield by a set of wavefield parameters determined directly from the seismic data. It can especially help in improving low fold data by its ability to improve the signal-to-noise ratio.

The first step in the work program was to verify data integrity, i.e. could the raw stack and raw migration be reproduced with the delivered CMP gathers and velocity information. The CMP gathers

(no. 1 in the list above) contained geometry as well as basic and residual statics information. The zero-phase operator (no. 6) was applied to the CMP gathers which were then stacked using the delivered RMS stacking velocity model (no. 4) and compared to the raw stack (no. 2). The newly stacked data was comparable to the delivered stack indicating correct application of geometry and statics and confirming the velocity model fitted the data. The same procedure was then repeated for the delivered raw pre-stack time migration stack (no. 3). CMP gathers with applied zero-phase operator (no. 1 / no. 6) were pre-stack migrated using the delivered pre-stack migration velocity model (no. 5) and again, the resulting seismic volume matched the delivered volume well.

Four different subsampling datasets were then extracted from the full set of CMP gathers resulting in a total of 5 datasets to be treated.

A. Original dataset without subsampling for comparison,
B. Every other shot position,
C. Every 3rd shot position,
D. Every other receiver position,
E. Every other shot and receiver position.

The shot and receiver line distances were kept constant for all the datasets. Shot and receiver numbers were used for computing, which stations were to be kept and which ones to be dropped. Table 2 shows a summary of the five scenarios along with the resulting point distances.

Table 2: Parameters of the five processing scenarios

Scenario	Shot domain	Shot point distance	Receiver domain	Receiver point distance
A	all	17.67 m	all	26.5 m
B	every 2nd	35.34 m	all	26.5 m
C	every 3rd	53.00 m	all	26.5 m
D	all	17.67 m	every 2nd	53.0 m
E	every 2nd	34.34 m	every 2nd	53.0 m

A complete re-processing for each of the datasets was not part of the project due to the limited time frame given in such a micro project. The basic question can be addressed without such individual re-processing even better as results for all subsampled data should be as identical as possible and differences can be contributed to the subsampling only. An individual re-processing could be carried out in a subsequent project to show the impact of the subsampling for e.g. denoising, statics computation and velocity estimation.

Figure 1 shows a zoom (4 km x 4 km) of the shot/receiver basemap for each of the scenarios. The nominal fold of coverage map for each of the scenarios is shown in Figure 2. It becomes clear that dropping every other shot or receiver cuts the nominal fold in half (scenarios B & D). Nominal fold for scenario C is 1/3 and for scenario E 1/4 of the original fold.

For each of the five scenarios the input data was pre-stack time migrated. In addition, CRS processing was applied to each of the five input datasets with subsequent pre-stack time migration. IEP GmbH provided a set of interpreted seismic horizons as visible in Figure 3. Top Purbeck (light blue) which is close to the top of the geothermal reservoir and the shallowest horizon Top Kirchberger Schichten (green) were selected for creating horizon slices from the computed seismic volumes.

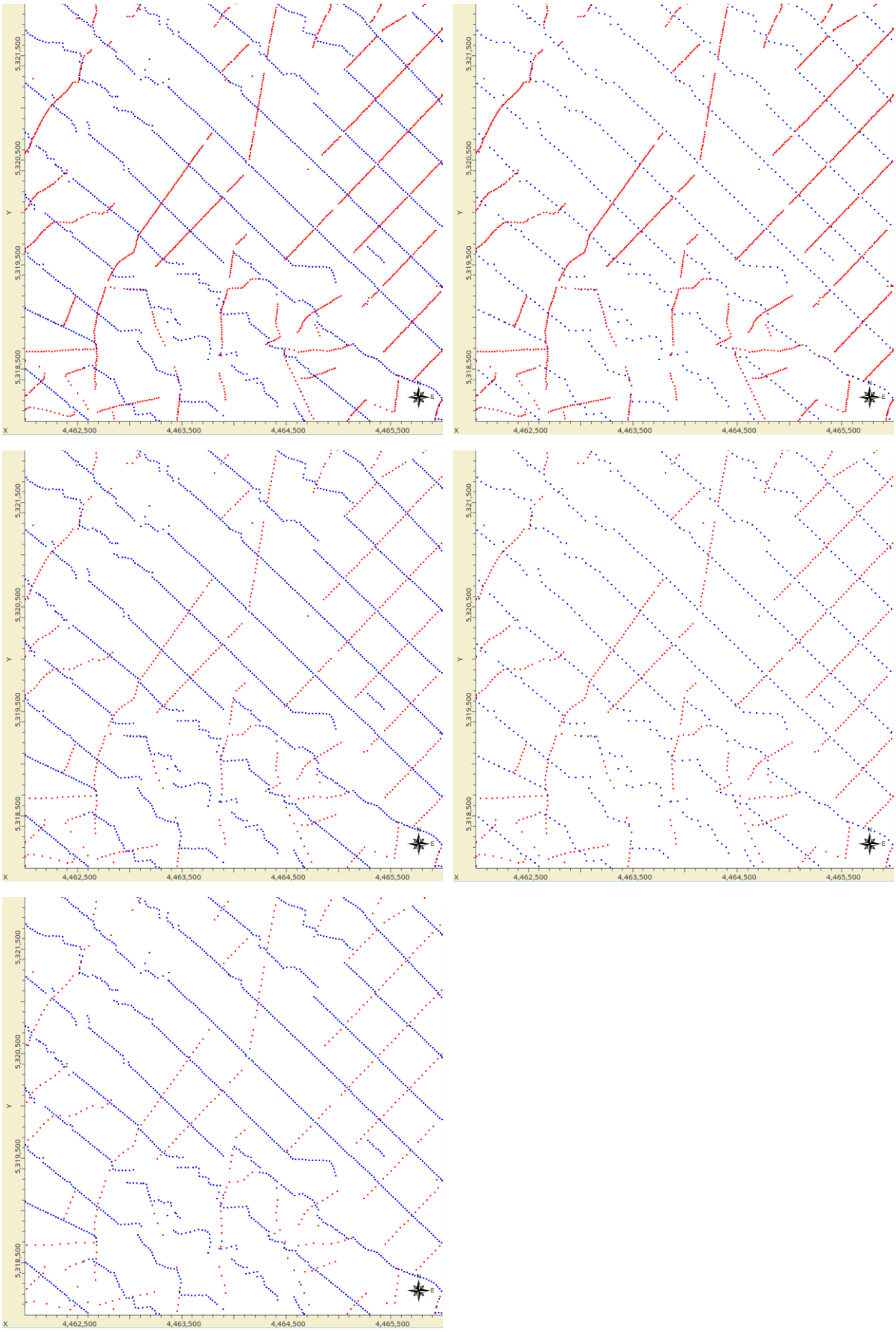


Figure 1: Zoom of shot/receiver basemap (4 km x 4 km) for scenario A (top left), B (middle left), C (bottom left), D (top right) and E (middle right))

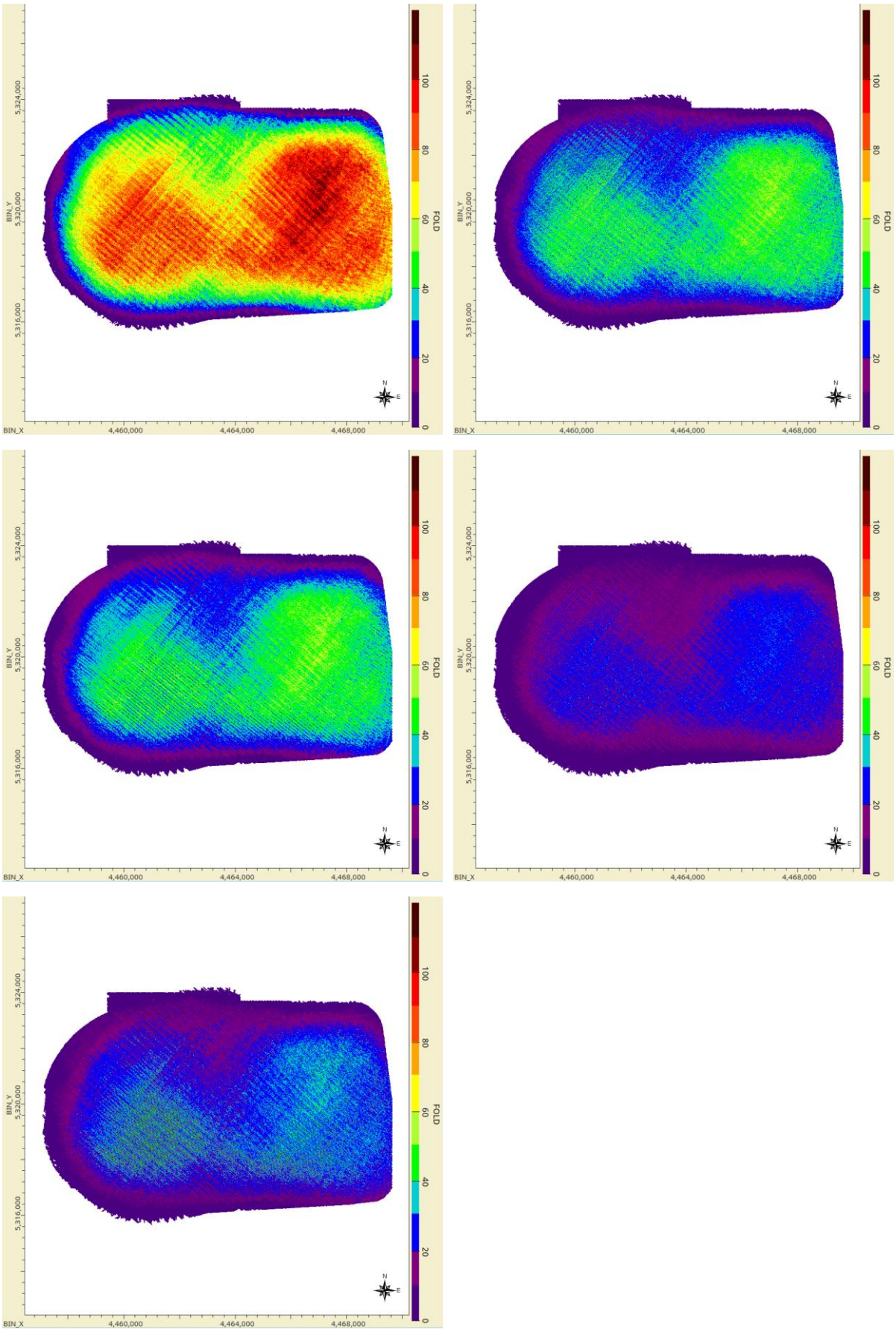


Figure 2: Fold of coverage map for scenario A (top left), B (middle left), C (bottom left), D (top right) and E (middle right))

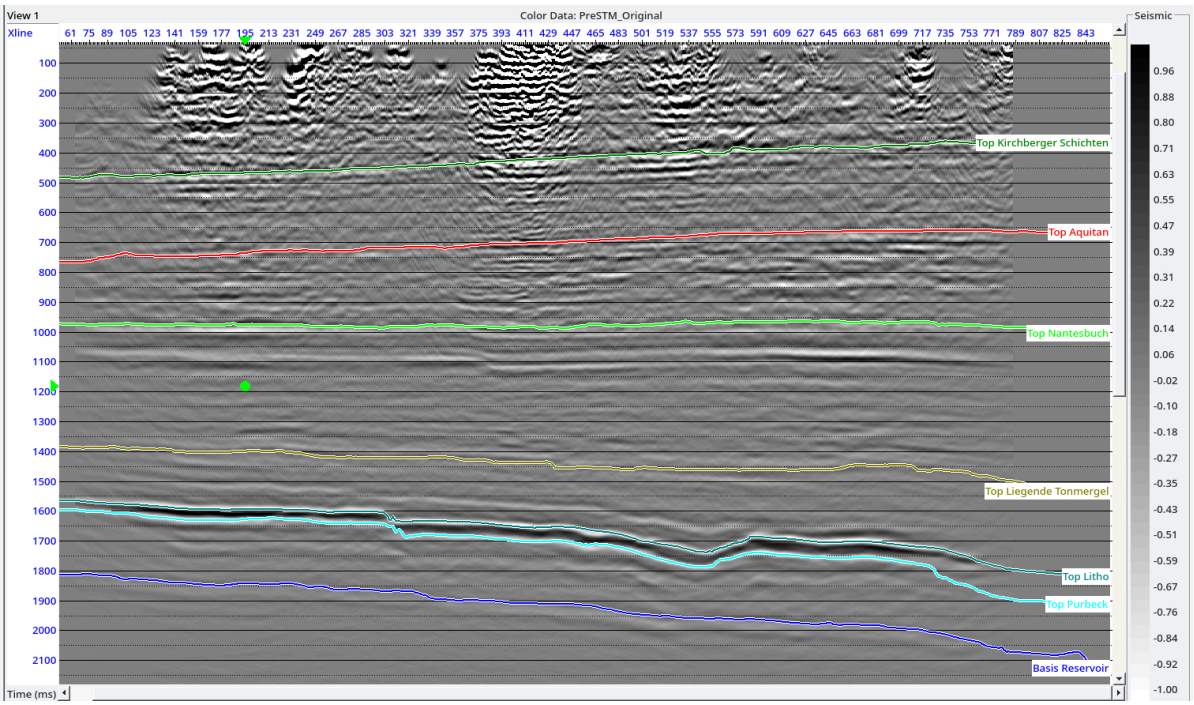


Figure 3: Inline 380 of scenario A, no CRS, with horizon interpretation

3 Results

Results of the work are presented in the following displays of horizon slices and cross sections. In addition to the amplitude displays of the horizon slices, the AVO gradient was selected as a pre-stack attribute that can easily be extracted from the seismic data without much a-priori knowledge of the background geological model. AVO intercept and gradient are two pre-stack seismic attributes which are used to evaluate changes of reflection amplitude with reflection angle. The gradient provides information about Poission ratio contrasts and thus changes in fluid/lithology.

Figure 2 shows the decrease of nominal fold of the data, and one would expect an equivalent drop of quality for the seismic image. However, this is not the case. Figure 4 compares a section of the original geometry A and the coarsest geometry E, i.e. the one for which both, every other shot and every other receiver were dropped. In addition to the standard processing result a CRS processed PreSTM is also shown for both geometries. It is obvious that the image quality decreases for the subsampled data, especially for the shallow section and the edges of the survey. For the target horizon such a decrease in quality is less obvious. The CRS processed versions both show a significant increase in signal-to-noise ratio and are very similar. The increase is most obvious in the shallow section and towards the edge of the survey where nominal fold is dropping. That means the CRS method can produce a similar image quality as long as the input geometry does not drop below the parameters required by subsurface geology. Even the subsampled scenario E of CRS is of better quality than the original geometry result for two-way travel times bigger than about 200 ms. In the shallowest section the near offsets of the subsampled geometry are obviously missing and cannot be reconstructed. The increase in signal-to-noise ratio in the CRS versions comes along with an increase in frequency content: subtle reflections that were not resolvable on the original results due to noise issues could now be resolved as a separate reflection.

Figure 5 compares a horizon slices along “Top Purbeck” for the standard PreSTM results of all geometries. Differences are not very obvious except towards the edge of the survey. Figure 6 shows

results for the CRS PreSTM of all five geometries along “Top Purbeck” horizon. Again, differences are negligible within the CRS versions. Subsurface structure of the CRS and non-CRS results is identical with less noise visible on the CRS data. The same comparison for the shallower horizon “Top Kirchberger Schichten“ is shown in Figures 7 and 8. For this horizon differences between the subsampled geometries become more visible for the non-CRS PreSTM. Lineaments which could be interpreted as fault planes are related to directional noise which is e.g. visible in the shallow section of Figure 4. After application of CRS processing, differences within the CRS products are once again negligible. Noise and artificial lineaments were successfully removed from the result using the CRS processing method.

It was then investigated if the observed behavior can be extended from the amplitude as a post-stack attribute to pre-stack attributes, too. The AVO gradient was chosen as it can be computed without knowledge of a rock property model. In AVO the amplitude of each pre-stack trace is extracted at a certain time and plotted against the square of the sinus of the offset of the trace. In hydrocarbon investigations the sign of the gradient could indicate presence of hydrocarbon pore content. In general, pre-stack attributes could be used for rock property or pore content description. It is therefore desirable to ensure good quality of pre-stack attribute extraction for reliable reservoir characterization work.

Results for “Top Purbeck” for the AVO gradient computed from standard (Figure 9) and the CRS PreSTM gathers (Figure 10) show a similar behavior as the post-stack attribute amplitude did. The standard results become noisier as the pre-stack traces contain a bigger amount of noise. Therefore, the decrease in quality of the AVO gradient with sparser geometry is more obvious as for a post-stack attribute. The CRS result once again does not show much of a difference. The result of the coarsest geometry E is even better, i.e. less noisy, than the result of the original geometry without CRS processing.

Finally, it was checked whether a processing on the native acquisition grid might offer an advantage in lateral resolution in comparison to the grid chosen for the initial 2018 processing. While the processing grid was chosen to be 15 m x 15 m the nominal grid would have been 8.84 m x 13.25 m. Figure 11 compares the results of the horizon slice “Top Purbeck” for the scenario A pre-stack data migrated to both grids. As expected, there is no increase in lateral resolution despite the significantly smaller grid size in one direction. That is in line with the fact that no additional information can be achieved if the acquisition bin size is deliberately chosen smaller than the required bin size which had been determined in acquisition design. Such choice only adds to acquisition costs without any value.

The results achieved in this study clearly show the opportunity of reducing effort in seismic acquisition if a modern, advanced processing flow is applied to the data.

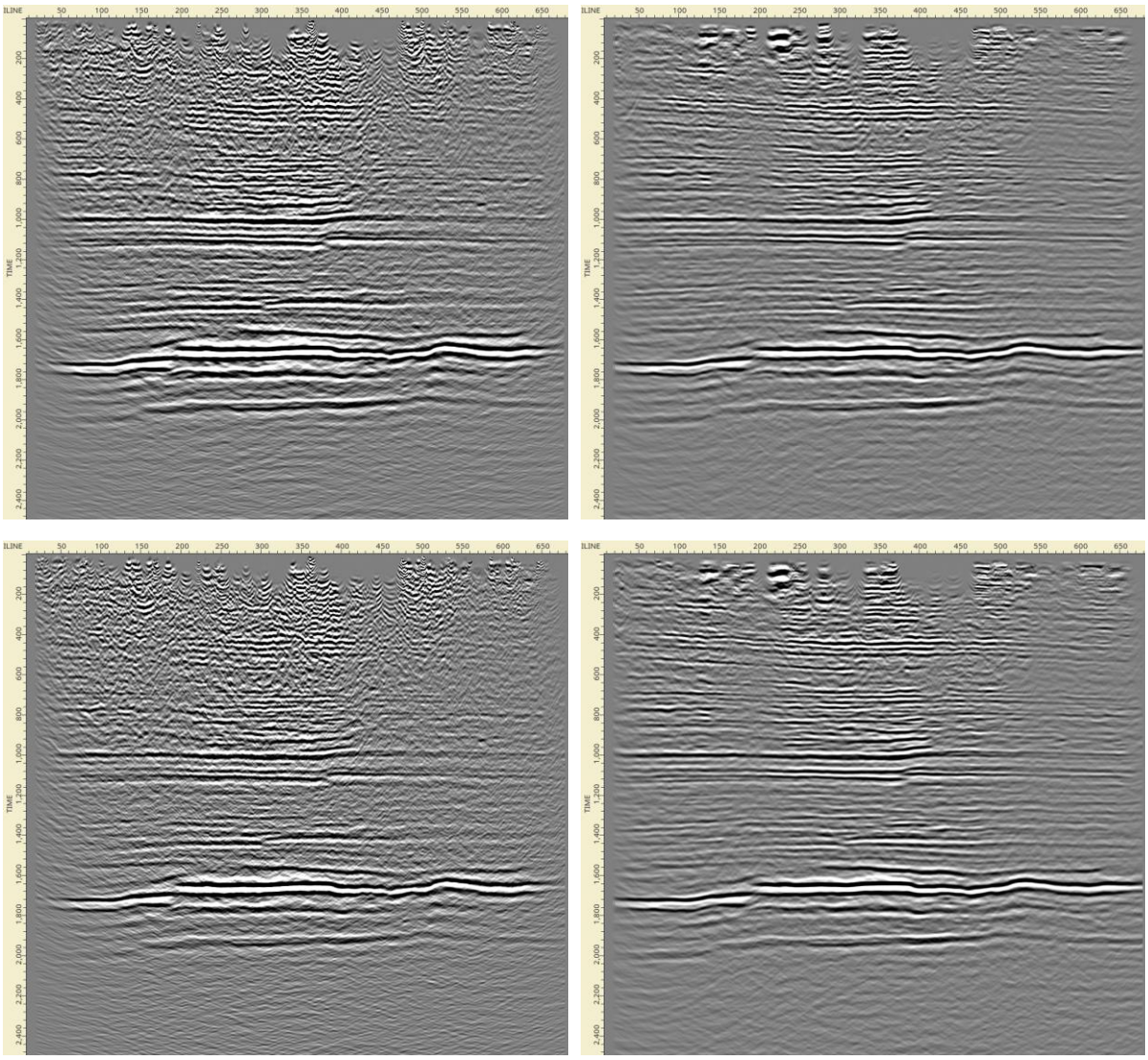


Figure 4: PreSTM result of scenario A (top left), PreSTM result of scenario E (bottom left), CRS PreSTM result of scenario A (top right) and CRS PreSTM result of scenario E (bottom right)

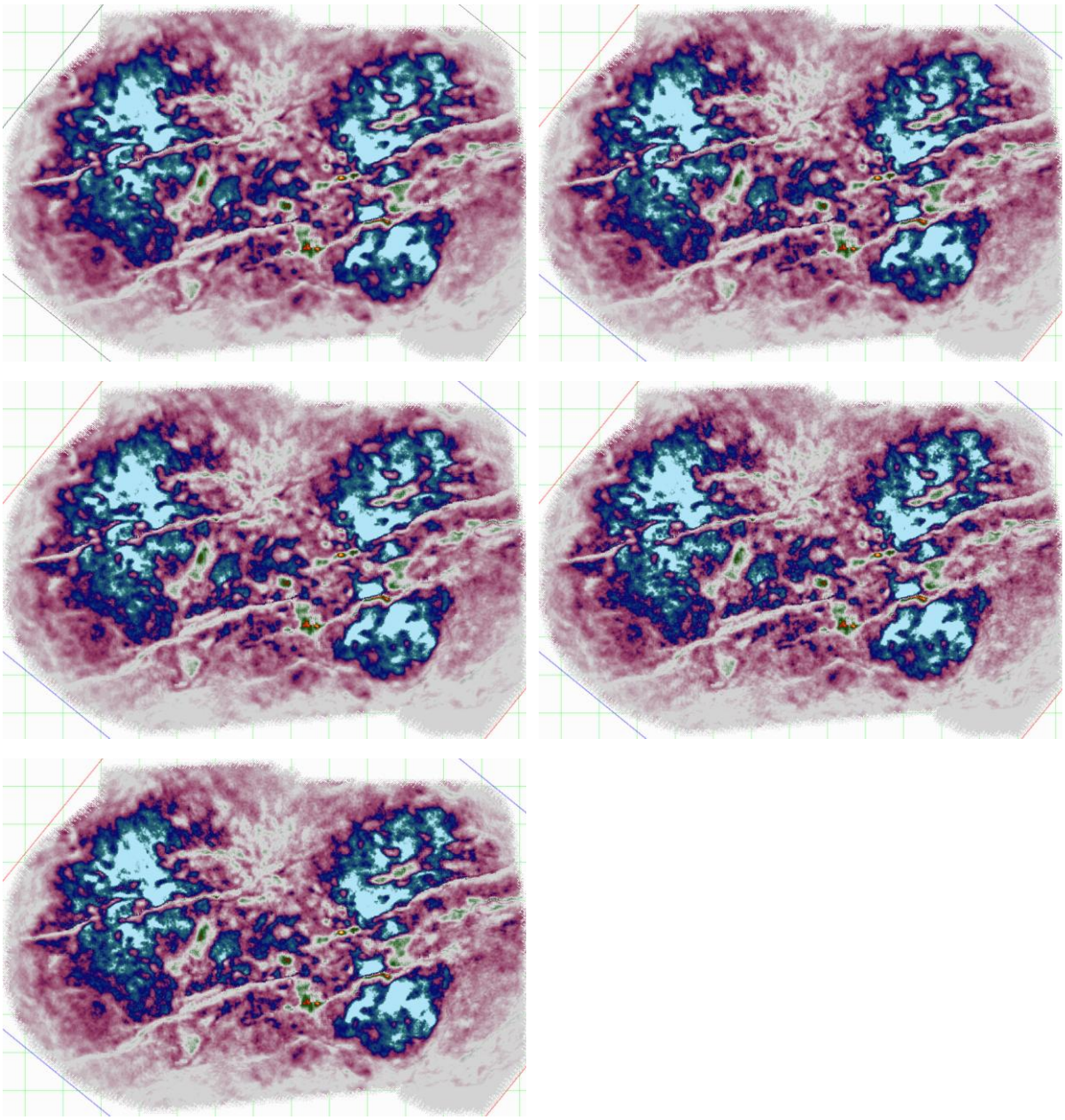


Figure 5: Top Purbeck horizon slice of PreSTM image of scenario A (top left), scenario B (middle left), scenario C (bottom left), scenario D (top right) and scenario E (middle right)

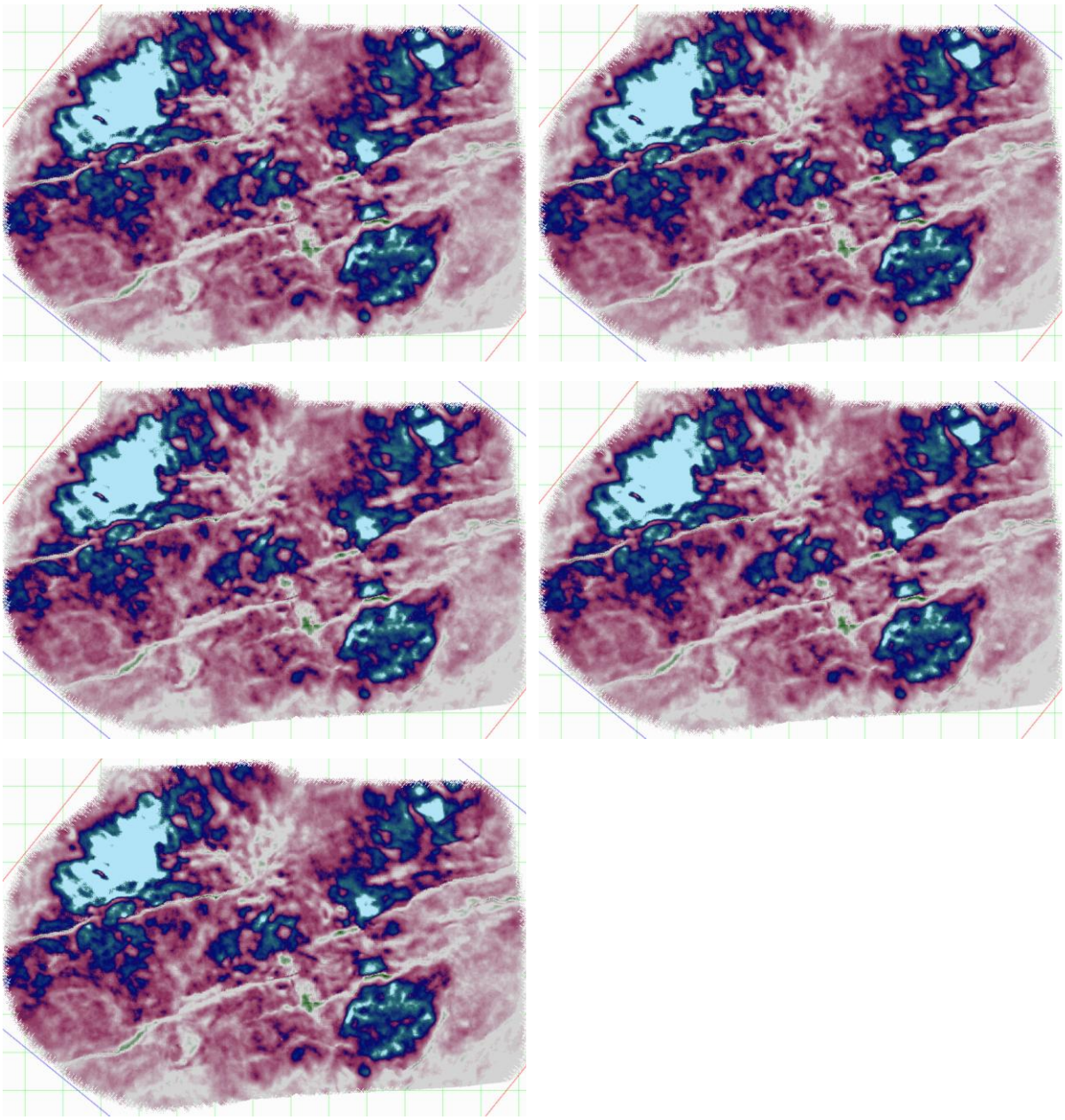


Figure 6: Top Purbeck horizon slice of CRS PreSTM image of scenario A (top left), scenario B (middle left), scenario C (bottom left), scenario D (top right) and scenario E (middle right)

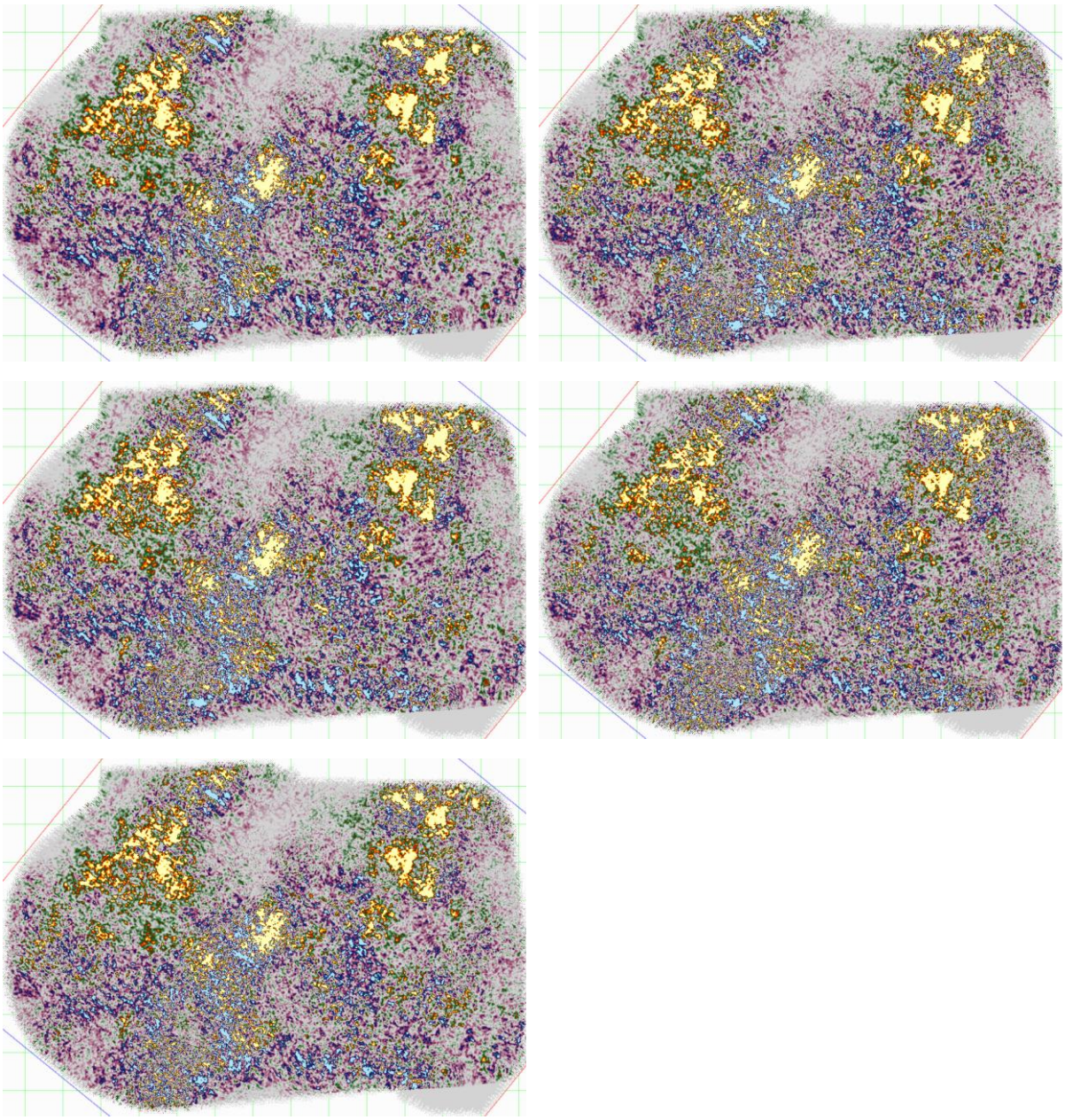


Figure 7: Top Kirchberger Schichten horizon slice of PreSTM image of scenario A (top left), scenario B (middle left), scenario C (bottom left), scenario D (top right) and scenario E (middle right)

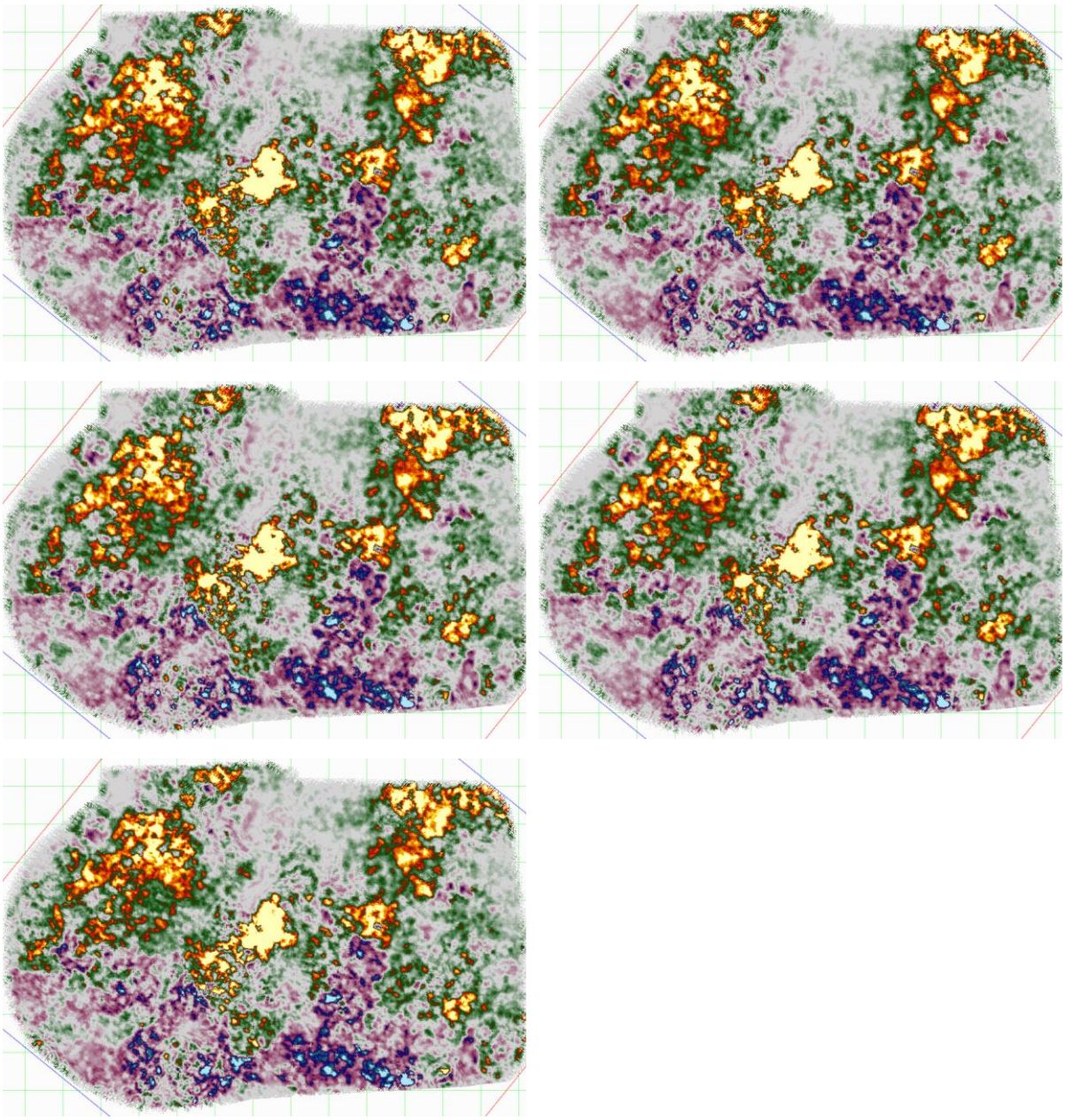


Figure 8: Top Kirchberger Schichten horizon slice of CRS PreSTM image of scenario A (top left), scenario B (middle left), scenario C (bottom left), scenario D (top right) and scenario E (middle right)

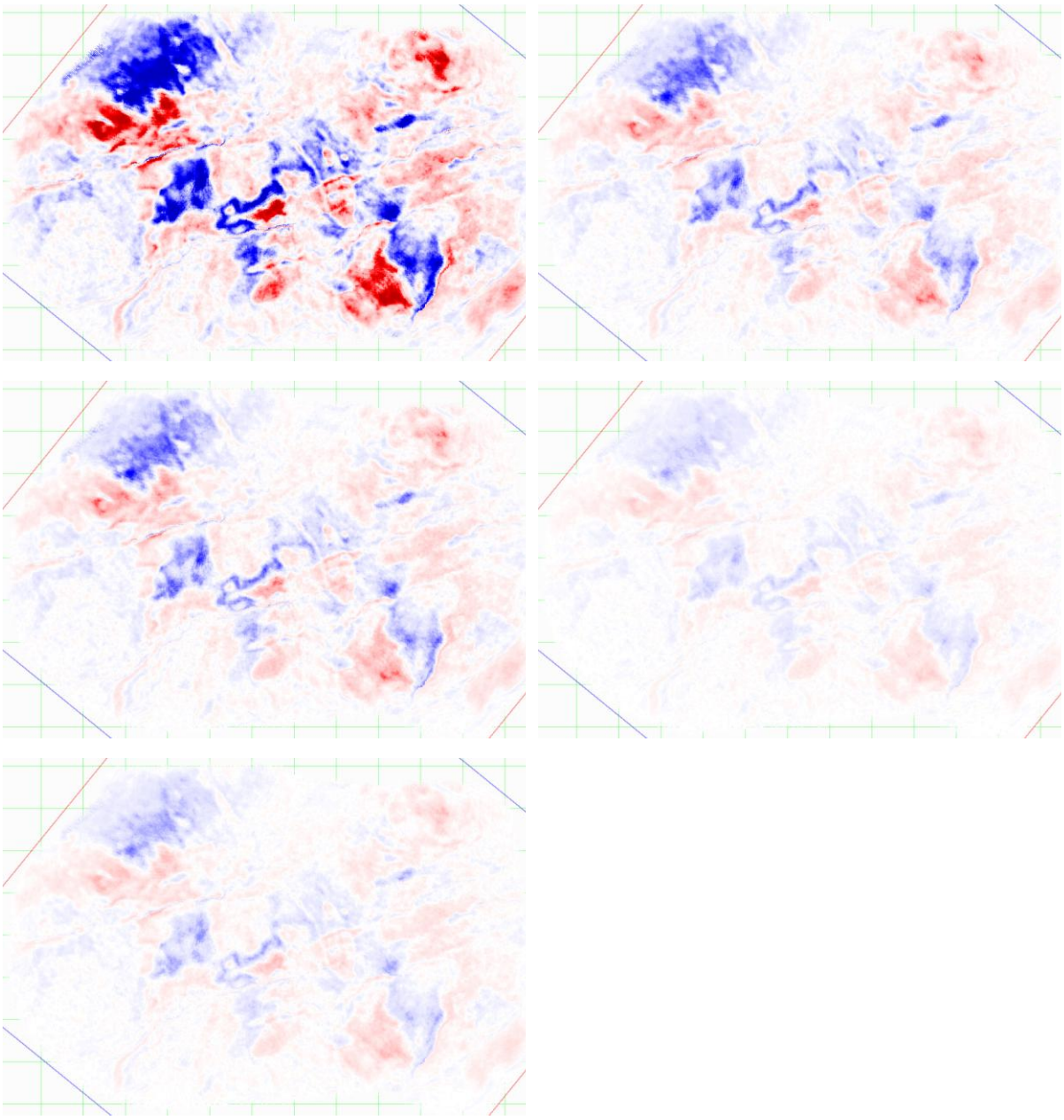


Figure 9: Top Purbeck horizon slice of AVO gradient of scenario A (top left), scenario B (middle left), scenario C (bottom left), scenario D (top right) and scenario E (middle right).

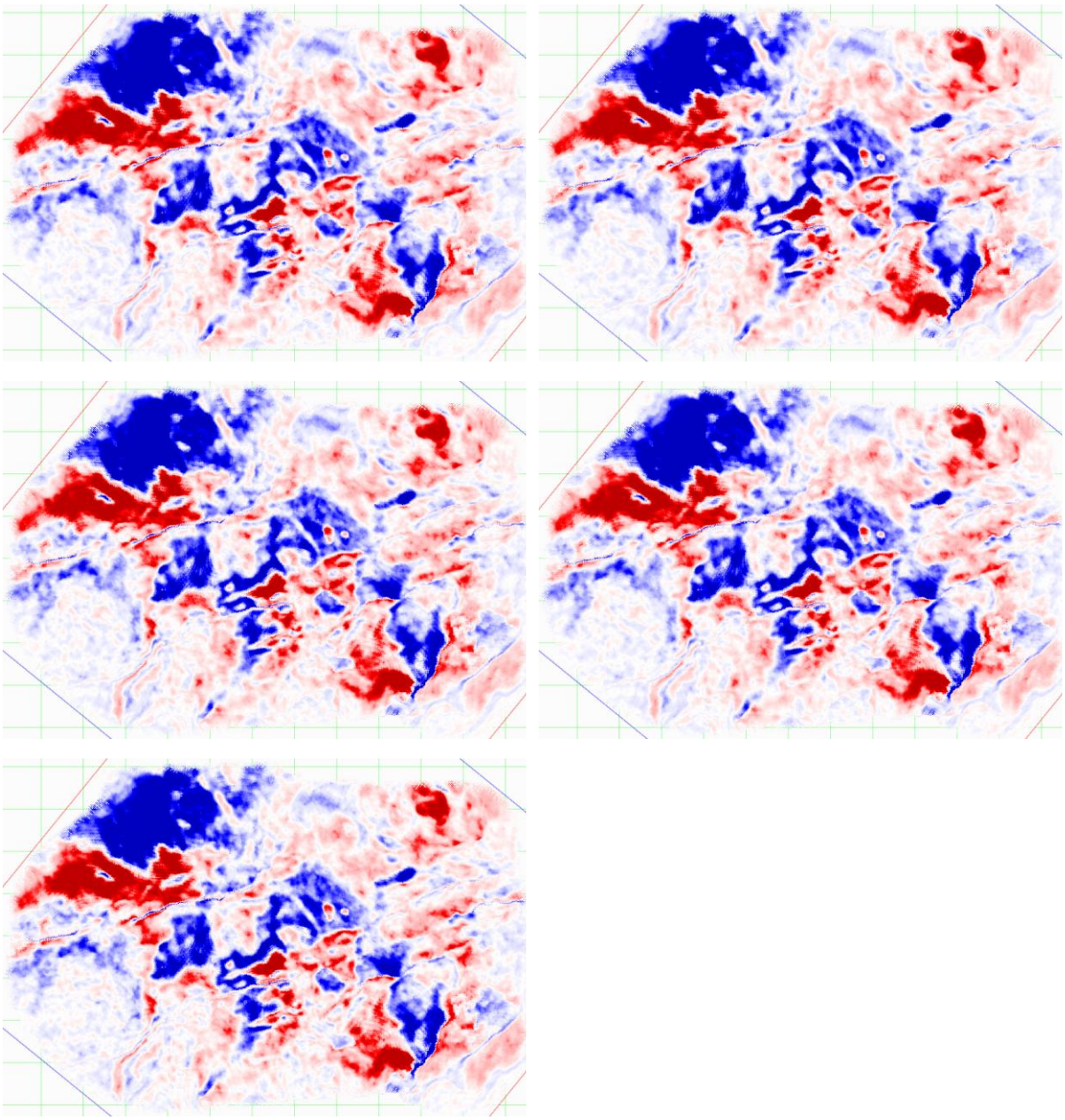


Figure 10: Top Purbeck horizon slice of CRS AVO gradient of scenario A (top left), scenario B (middle left), scenario C (bottom left), scenario D (top right) and scenario E (middle right)

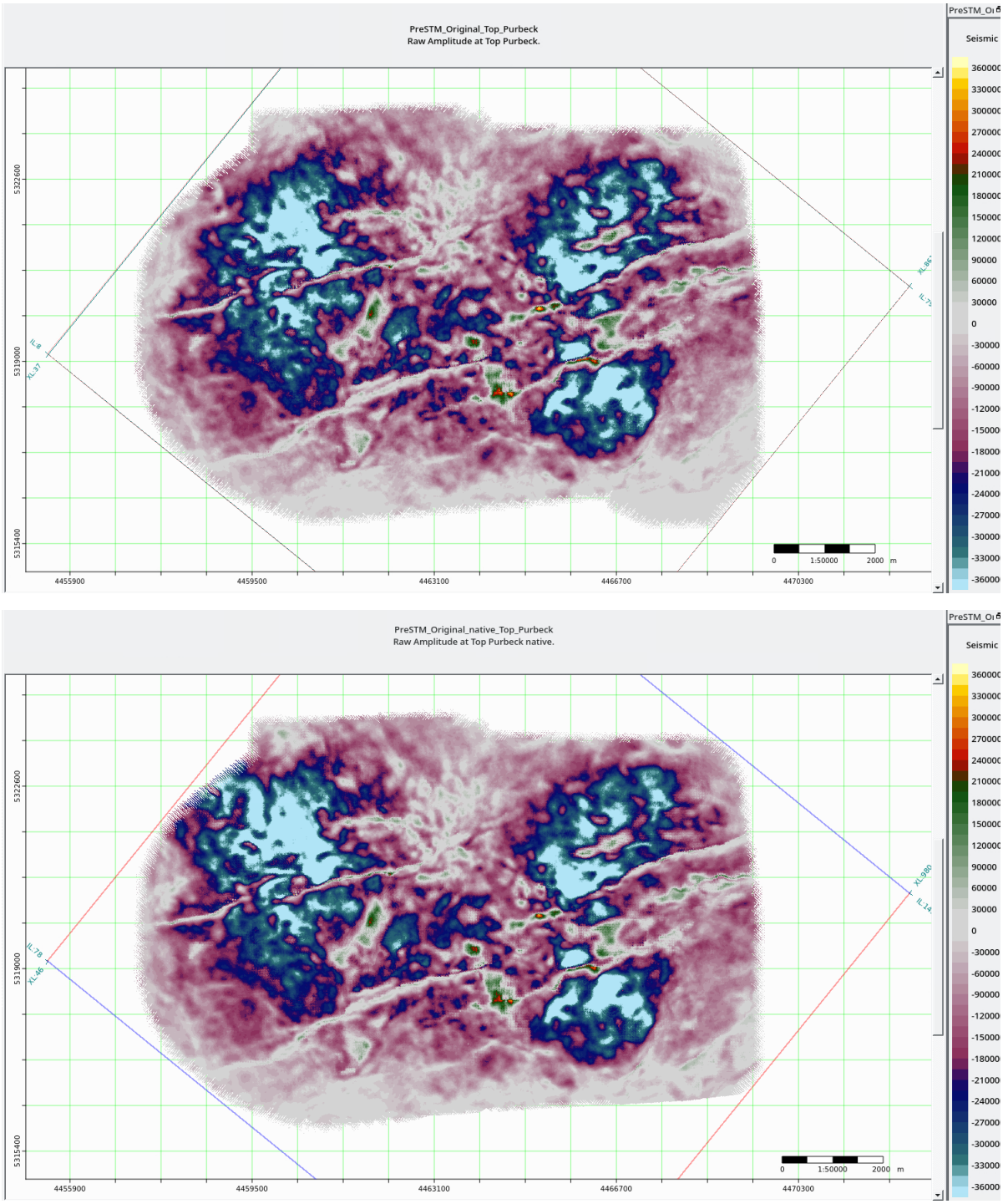


Figure 11: Top Purbeck horizon slice of PreSTM of scenario A on 15 m x 15 m grid (top) and 8.84 m x 13.25 m grid (bottom)

4 Summary

The research project OPTAC (OPTimized ACquisition) showed that similar results in seismic imaging can be achieved with more economical acquisition designs. This holds particularly true if a lower fold or less dense acquisition is combined with modern seismic data processing methods such as the Common Reflection Surface (CRS) method. The same or even better quality could be achieved for both the seismic image as well as the pre-stack seismic attribute AVO gradient after the application of CRS processing.

Hydrothermal geothermal exploration usually tries to avoid complex geological settings. For such conditions modern seismic data processing methods seem to be a perfect tool to reduce effort in seismic data acquisition. The actual acquisition design is of course subject to a detailed acquisition design study considering the underlying geology as well as operational considerations relevant for the acquisition area. Complex subsurface structures, steep dips, strong impedance contrasts and other geological challenges will naturally result in a denser acquisition than required for simpler targets. However, if vintage seismic is of relatively good quality there is no good reason to recommend a so called high-fold, high-resolution seismic acquisition campaign. The key parameters for seismic acquisition design remain the depth of the main target, the desired lateral resolution and the depth of the shallowest target to be imaged. This set of imaging requirements is fully defining the acquisition parameters. Bin fold or point density are dependent parameters and should not be considered the driver for a choice of parameters.

Modern seismic data processing methods are not considered in seismic data acquisition literature. Such literature was published in the early 2000s when the processing methods were not yet fully available. An update of acquisition design including modern processing methods is missing. Concerns about signal-to-noise ratio are often reasons for high-fold seismic acquisition. It must be pointed out that acquisition effort needs to be increased to the power of 2 for a linear increase of signal-to-noise ratio. This approach is therefore not very effective and tremendously expensive. The OPTAC project has shown that a reduction of bin fold can successfully be recovered by processing methods resulting in less acquisition cost and faster project turn-around.

Based on the results of this project we estimate a possible reduction in acquisition costs of at least 1/3 without a loss in seismic image quality. This estimate assumes that acquisition roughly consists of 10% fixed cost for mobilization/demobilization and 90% of variable cost according to point density. It has been shown that dropping every other shot point and every other receiver point led to comparable results for the target horizon. With the application of CRS processing this had been successfully extended to the low fold zone, i.e. quality of shallow horizons and edges of the survey were comparable, too, after application of CRS processing. Such reduced acquisition geometry comes with only 1/4 of the point density which translates into a cost saving of a maximum of 67% in comparison to the original setup. Such high savings cannot be expected in reality, though. For smaller acquisitions the fixed cost is usually slightly increasing. Furthermore, it must be pointed out that the reduction in cost and turn-around time is not limited to the seismic acquisition but will also apply for permitting.

The above discussed reduction in effort is related to point density only. Further reduction due to a detailed ray tracing study is possible when the required margin around the full fold survey can be selected smaller than estimated from initial acquisition design. Only a ray tracing study can reveal the actual amount of margin required around the full fold area. Per each 500 m of saved margin a reduction of 10-15% of the total size of the acquisition can be achieved.

As for seismic data processing, the additional cost and effort for CRS processing might offset the savings in both time and cost. This is a small sacrifice in comparison to the cost saved in acquisition. A rule of thumb assumes processing cost to be in the order of 10% of acquisition cost.

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