Pre-Stack Depth Migration and Reverse Time Migration Processing Test

SCAN Line L2EBN2019ASCAN002

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Summary

EBN performed a PreSDM processing test on SCAN line L2EBN2019ASCAN002 in order to compare this processing methodology to the PreSTM base processing of the SCAN survey. The PreSDM and RTM processing resulted in some improvements of the seismic image, however, the differences compared to the PreSTM are limited. In view of the additional time and cost effort needed to arrive at the PreSDM (or RTM) product and the regional geological objectives of the SCAN survey it is concluded that the PreSTM processing already arrives at good results. PreSDM and/or RTM processing may still be worthwhile at a later stage for specific imaging challenges.

Revision history

Revision Number	Purpose	Date
00	For review	19/03/2021
01	For approval	06/04/2021

Approval

Name	Role	Function title	Date & Approval
Henk van Lochem	Author	Consultant Geoscientist	06/04/2021, approved
Johannes Rehling	Author	Senior Geophysicist	06/04/2021, approved
Marten ter Borgh	Author	Principal Geoscientist	06/04/2021, approved
Guido Hoetz	Reviewer	Geoscience advisor	21/04/2021, approved

Introduction and Objectives

In the period 2019–2022, EBN is acquiring and processing a large 2D seismic survey in the central and southern part of the Netherlands. This survey, called SCAN, is specifically aiming at geothermal exploration. The base processing sequence of these 2D lines includes Pre-Stack Time Migration (PreSTM). Since the advent of better migration algorithms and the availability of more computer power Pre-Stack Depth Migration (PreSDM) has become a common procedure for processing seismic data. Especially on 3D seismic data shot for hydrocarbon exploration and development this technique is commonly being applied.

During the tender of the processing a broad band PreSTM processing flow was selected as base processing flow. A PreSTM is known to be a cost-efficient migration algorithm that usually provides good imaging quality, except for structurally complex settings such as pre-salt. More advanced imaging techniques such as PreSDM or Reverse Time Migration (RTM) were included in the processing tender as optional processing steps.

In order to investigate how effective the PreSTM processing is and to evaluate how much a PreSDM processing might add to fulfill the SCAN objectives, a processing test was performed on one of the SCAN lines. In addition to the regular PreSTM processing workflow, a Kirchhoff PreSDM and a PreSDM migration using Reverse Time Migration (RTM) processing workflow were performed.

For the test SCAN line 2 (L2EBN2019ASCAN002) was selected (Figure 1). This line runs from Boxtel in Noord-Brabant in the southwest to the Bronkhorst 3D area in Gelderland in the northeast. The total length of the line is 82.6 km. It crosses several tectonic domains: the Roer Valley Graben, the Peel-Maasbommel High and the Central Netherlands Basin. Three legacy wells are located on the line; HSW-01(S1) in the Roer Valley Graben with a Total Depth (TD) in the Lower Germanic Trias Group, NVG-01 on the Peel-Maasbommel High with a TD in the Limburg Group and well AHM-01 in the Central Netherlands Basin which TD-ed in the Middle North Sea Group. Large faults, including the Peel Boundary Fault and significant velocity contrasts had been observed on this line making it a good subject for this processing test.

For the input of the velocity modelling a seismic interpretation of key horizons and faults was provided to the processing contractor (DownUnder GeoSolutions, DUG). These horizons are summarized in Table 1 below and displayed in Figure 4.

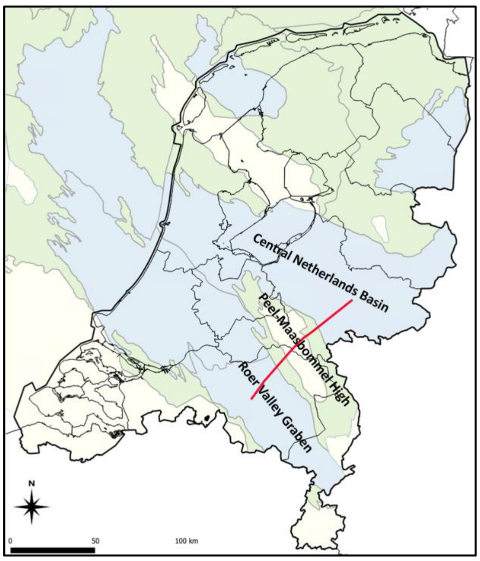

Figure 1 Location of SCAN line 2 with respect to the main geological elements

Base Upper North Sea Gp.	
Base Lower North Sea Gp.	
Base Chalk Gp.	
Base Rijnland Gp.	
Base Schieland Gp.	
Base Altena Gp.	
Base Lower Germanic Trias Gp.	
Base Zechstein Gp.	
Base Limburg Gp.	

Table 1 Horizons interpreted for velocity modelling input

This report is intended to give a concise review of the results of the PreSDM processing test considering the SCAN objectives. Since SCAN is a regional exploration program the most important objectives are the depiction and recognition of the main geothermal reservoirs, in such a way that reliable regional maps can be made on which geothermal leads and prospects can be defined. The deepest geothermal target in the SCAN survey is the Dinantian Limestone, which can be present at considerable depths, up to 8 km. Note that for geothermal exploration the definition of a prospect does not require the proof of a closed structure, which is often the most critical aspect in the definition of a hydrocarbon prospect. For a geothermal prospect, reservoir quality and thickness are often the most important factors, while detailed structural definition is less decisive. For the planning of geothermal exploration wells on the SCAN lines, more seismic data will be needed including (reprocessed) legacy data and, depending on the location, additional local 2D lines or a (local) 3D seismic survey. Planning well trajectories is beyond the scope of this evaluation.

Processing workflows

As mentioned in the introduction, a PreSTM processing flow was the selected base processing flow. The following chapters gives a high-level processing summary for the PreSTM, PreSDM and RTM imaging, for detailed information the reader is encouraged to download DUG's respective processing reports from NLOG.

PreSTM processing flow (as base processing)

- Data import and geometry setup
- Spherical divergence correction
- Geophone response correction
- Refraction statics
- 5 iterations of noise attenuation processes
- 1st pass surface consistent amplitude compensation: Source and receiver components
- Time-Frequency Denoise in different domains
- Inverse Q compensation
- Surface consistent deconvolution
- 1st pass velocity analysis (1 km)
- Wavelet transform denoise on shots
- 1st pass residual statics
- 2nd pass velocity analysis (1 km)
- 2nd pass residual statics
- Removal of spherical divergence
- 2 iteration of PreSTM velocity model updating
- Low cut filter: 2.5 Hz with 18 dB/octave slope prior to final PreSTM
- Anisotropic VTI Pre-Stack Kirchhoff Time Migration,
    - 3 km aperture length with time variant dip
- Radon demultiple
- Noise attenuation
- Trim statics
- Conversion to zerophase
- 2 more passes of noise attenuation
- Application of inner and outer trace mute and subsequent stacking
- Spectral broadening
- 3 more passes of noise attenuation
- Time-variant frequency domain filter
- Shift to final datum (NAP)

PreSDM processing flow

The data preprocessing for the PreSDM imaging was identical with the PreSTM preprocessing, except that one extra noise attenuation step was included between the 1st and 2nd pass of initial velocity picking.

As exact picking of the seismic events is crucial for the best possible velocity model building during the PreSDM, the data was zero phased prior to the first PreSDM iteration. The further PreSDM processing applied was as follows:

- Shift to PreSDM migration datum: 200 m smoothed topography
- 4 iterations of depth domain tomography
- Anisotropic VTI Pre-Stack Kirchhoff Depth Migration
    - 3 km aperture length with 60 degrees dip
    - Maximum depth 12 km

After the PreSDM imaging, the post-migration processing was again identical to the PreSTM processing flow.

RTM processing flow

The RTM used the same input gathers as the PreSDM as well as the final PreSDM velocity model. The RTM was run with a 40-degree angle mute on the input data and up to a maximum frequency of 100 Hz. As the output of the RTM is a stack rather than pre-stack image gathers, there was no further post-migration pre-stack data processing applied. The post-stack processing sequence as applied to the PreSTM data was applied to finalize the RTM processing.

Results

PreSDM & RTM processing products:

Similar to the PreSTM processing, the PreSDM processing included the delivery of matching datasets, such as

- Final near/mid/far & full PreSDM volumes, with and without AGC scaling (in time and depth)
- PreSDM velocity model with delta & epsilon fields (in time and depth)
- Associated raw stacks and pre-stack gathers

A complete list of processing products can be found in DUG's processing report.

The polarity convention of the seismic data is displayed in figure 2.

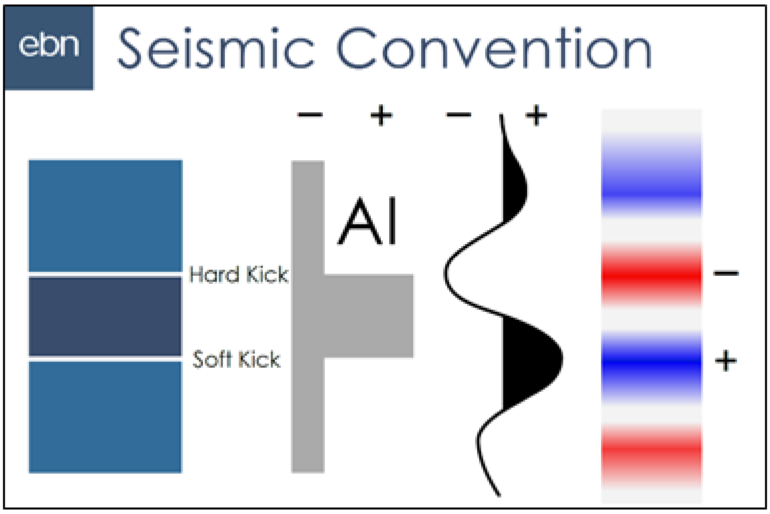

Figure 2 Seismic display convention

Comparison Full-stack data

The three migration methods were compared by focusing on the main differences in the seismic image results. For this the final full-stack Two-way-time (TWT) sections were used on which the same base processing was applied, including a pre- and post-stack Automatic Gain Control (AGC). So, for the PreSDM and RTM data the depth sections were converted back to TWT using the applied migration velocity data.

When comparing the three complete sections (Figure 3) it is obvious that the differences between the products are limited. The various reflective packages and main faults are very similar in appearance. A more detailed comparison is needed to show the differences between the migration outcomes.

The velocity fields of the PreSTM and PreSDM models are compared in Figure 4, where it must be noted that the PreSTM velocities are RMS velocities, while the PreSDM velocity model shows the interval velocity. The PreSDM velocity model shows clearly that the horizon and fault interpretation has been used in the model building.

For five locations (indicated on Figure 3) a more detail comparison was made of the three migration products. Interpreted reflectors on these sections are picked mainly since they can be auto-tracked with confidence, rather than that they represent key lithostratigraphic boundaries. The horizons were picked on the PreSTM sections and displayed on the RTM and PreSDM versions.

In Figure 5 the seismic data of the North Sea Group of the northeastern part of the section is compared. The interpretation of the base of the Lower North Sea Group deviates with a maximum of 10 ms TWT between the migration products, but generally the difference is smaller.

In Figure 6 the seismic data of the Triassic and Upper Carboniferous interval on the Peel-Maasbommel High in the central part of the section is compared. The maximum vertical difference observed between the migration products is 40 ms TWT. The reflector differences, however, can also be explained by lateral shifts of the reflectors due the migration process in the order of 100–200 m.

In Figure 7 the seismic data of the Lower North Sea Group and Schieland interval of the Roer Valley part in the southwestern part of the section is compared. The maximum vertical difference observed between the migration products is 10 ms TWT. The faults would not have been picked significantly differently on the PreSDM sections compared to the PreSTM section. The horizontal offset between fault interpretations on the three migration products would not be more than 100 m.

In Figure 8 the seismic data of the Limburg Group interval Central Netherlands part in the northeastern part of the section is compared. In the TWT interval 1400–1750 ms the PreSDM and RTM sections show a better reflector continuity than the PreSTM section.

In Figure 9 the seismic data of the Dinantian of Central Netherlands part in the northeastern part of the section is compared. In the TWT interval 2700–3100 ms the PreSDM and especially the RTM section shows an improved reflector continuity compared to the PreSTM section.

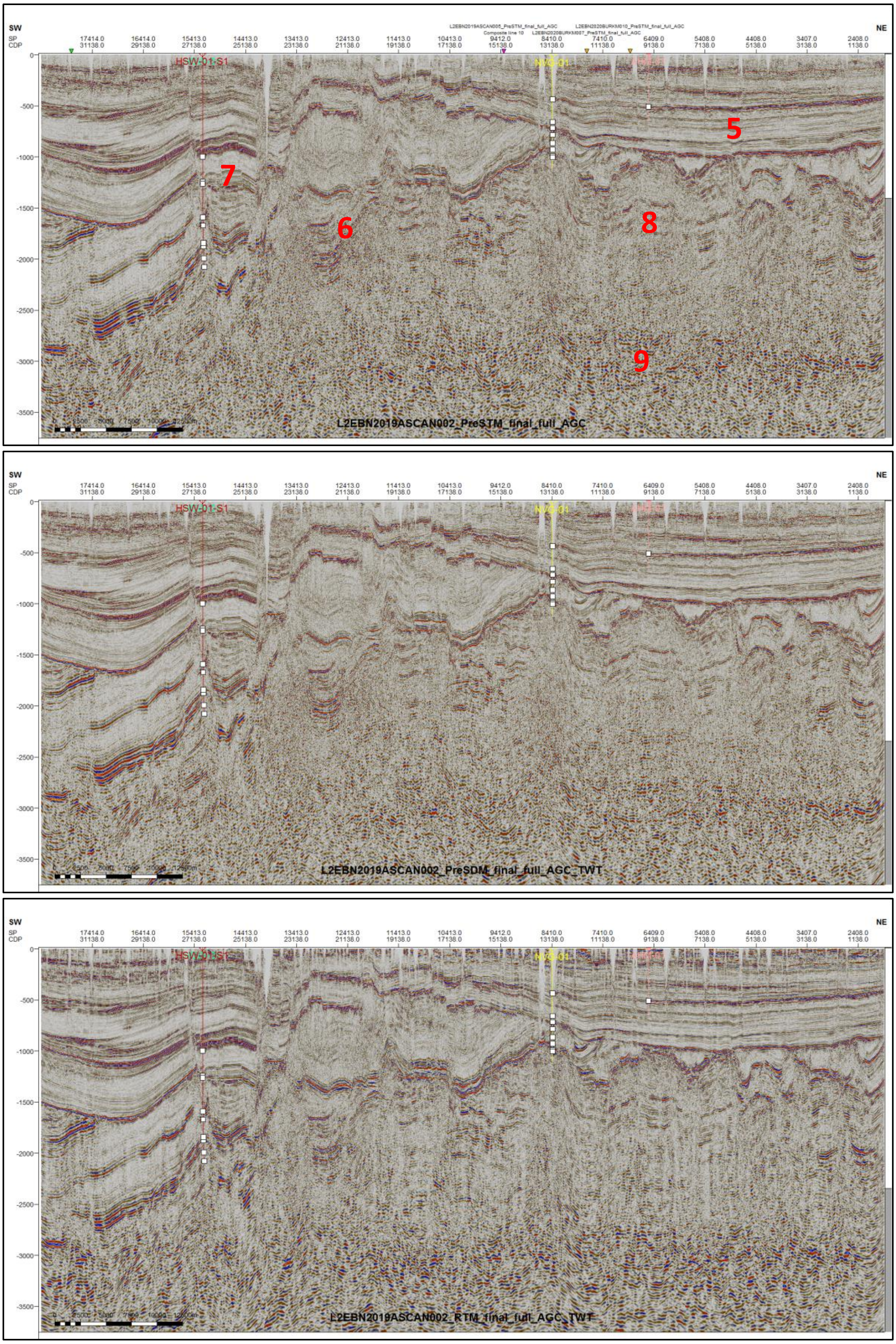

Figure 3 Comparison Final Full-Stack Two-way-Time (TWT) sections; top PreSTM section, middle PreSDM section and bottom RTM section. In the PreSTM section the numbers of the figures are displayed as an indication of the location for the various examples

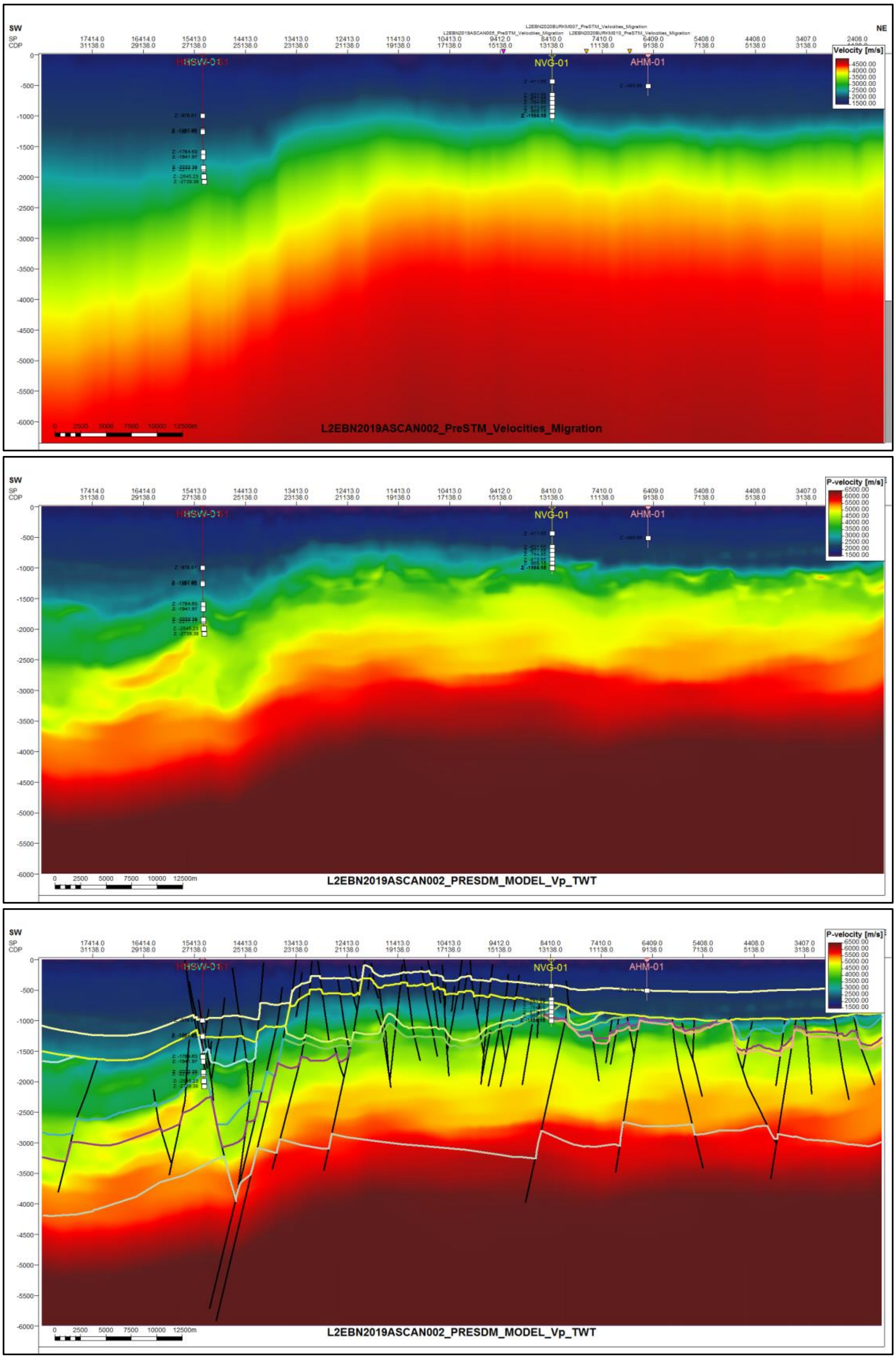

Figure 4 Comparison velocity models; top RMS migration velocity PreSTM, middle PreSDM Vp interval velocity and bottom PreSDM velocity model with horizon and fault interpretation overlain. Legend to horizons in Table 1.

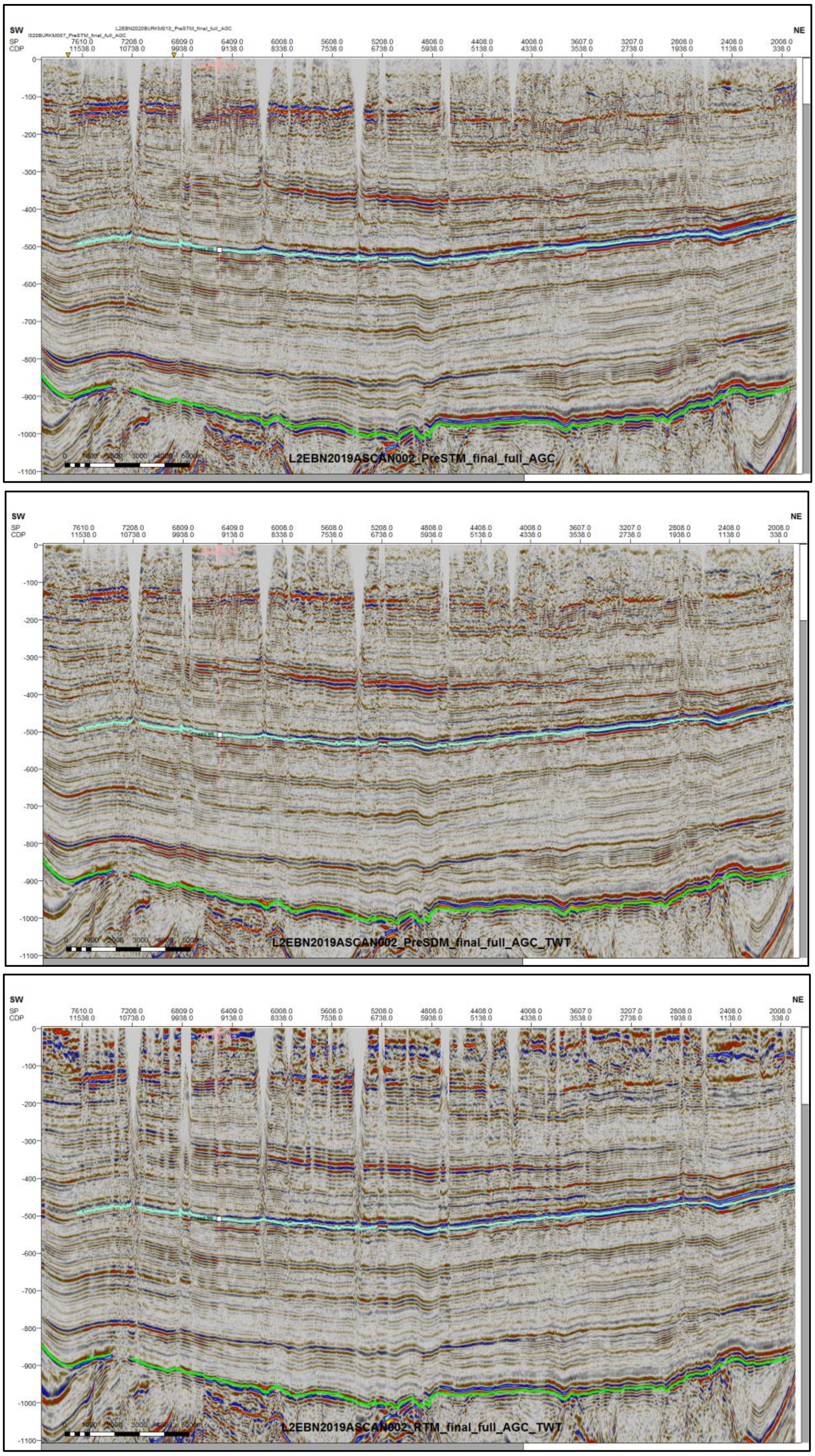

Figure 5 Comparison North Sea Group in Central Netherlands Basin part of section, interpretation auto-tracked on PreSTM section; top PreSTM section, middle PreSDM section and bottom RTM section. Two clear horizons were autotracked on the PreSTM and displayed on the other products. The horizons were not picked to represent a certain lithostratigraphic horizon

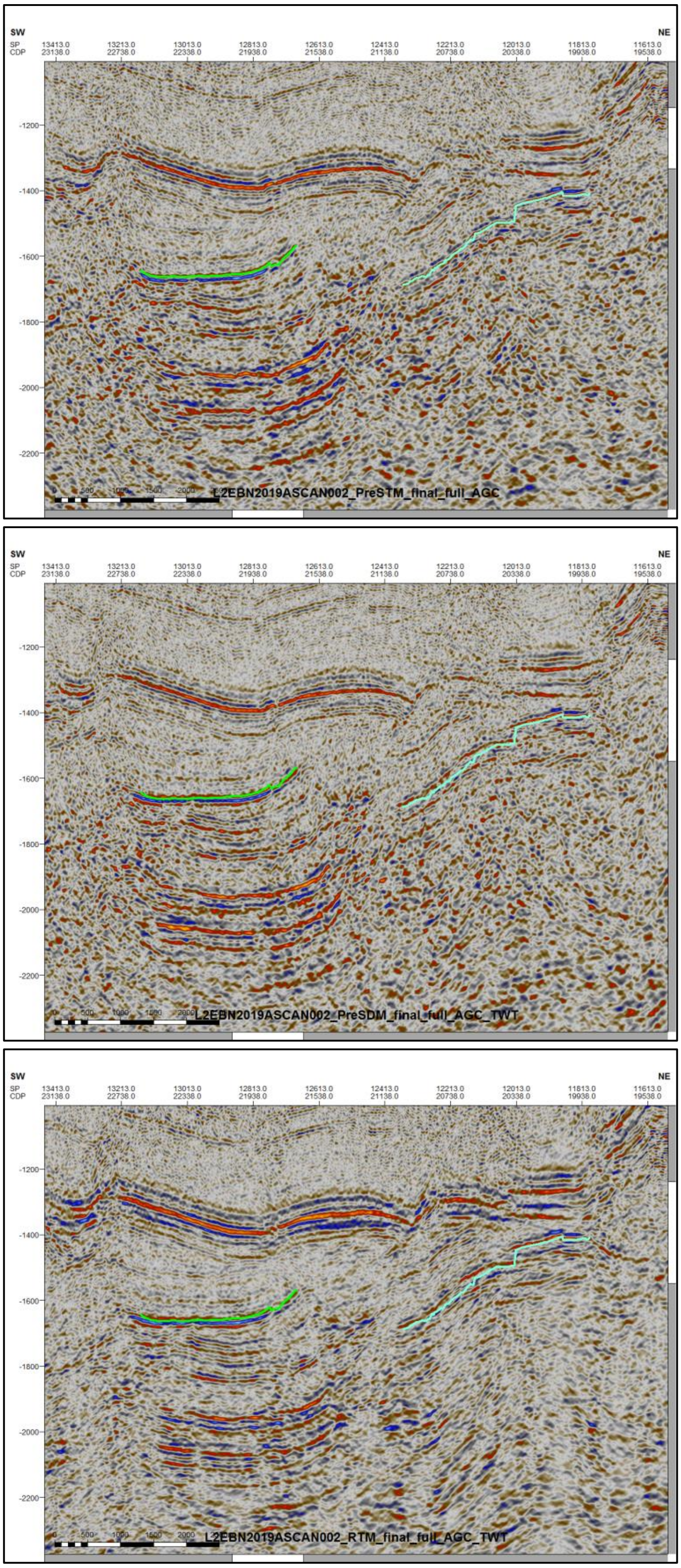

Figure 6 Comparison Triassic and Upper Carboniferous on Peel-Maasbommel part of section, interpretation auto-tracked on PreSTM section; top PreSTM section, middle PreSDM section and bottom RTM section

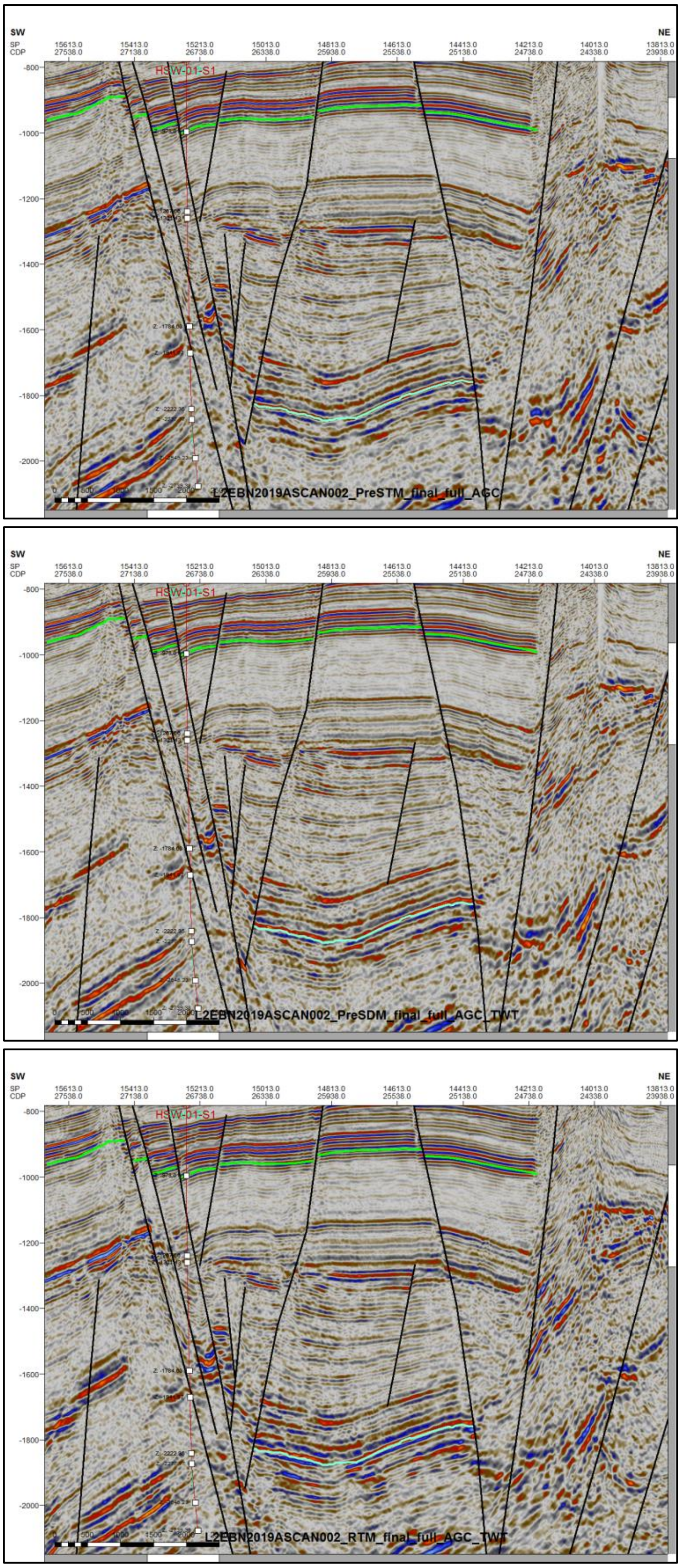

Figure 7 Comparison Lower North Sea Group to Schieland on Roer Valley Graben part of section, fault interpretation and auto-tracked horizons on PreSTM section; top PreSTM section, middle PreSDM section and bottom RTM section

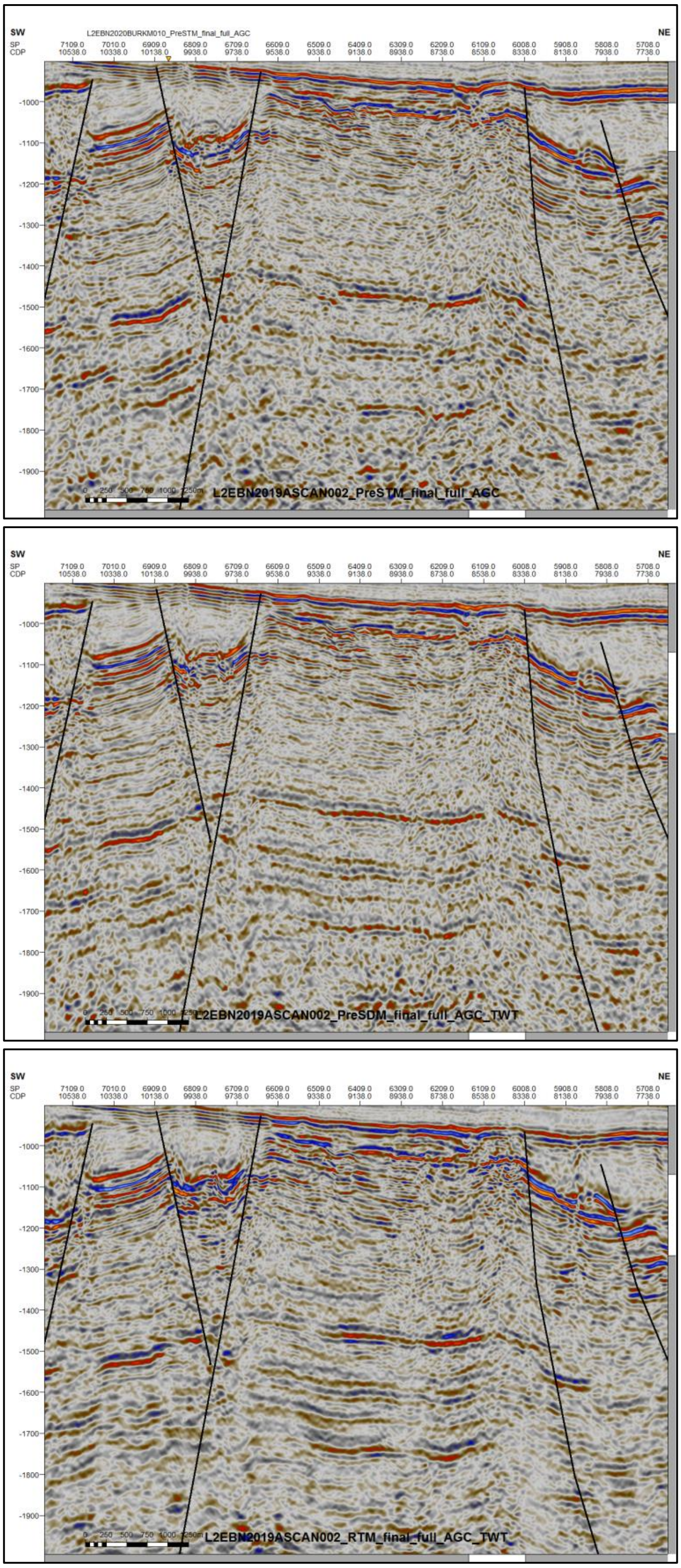

Figure 8 Comparison Limburg Group in Central Netherlands Basin part of section. Note the difference in continuity in the interval 1400–1750 ms; top PreSTM section, middle PreSDM section and bottom RTM section

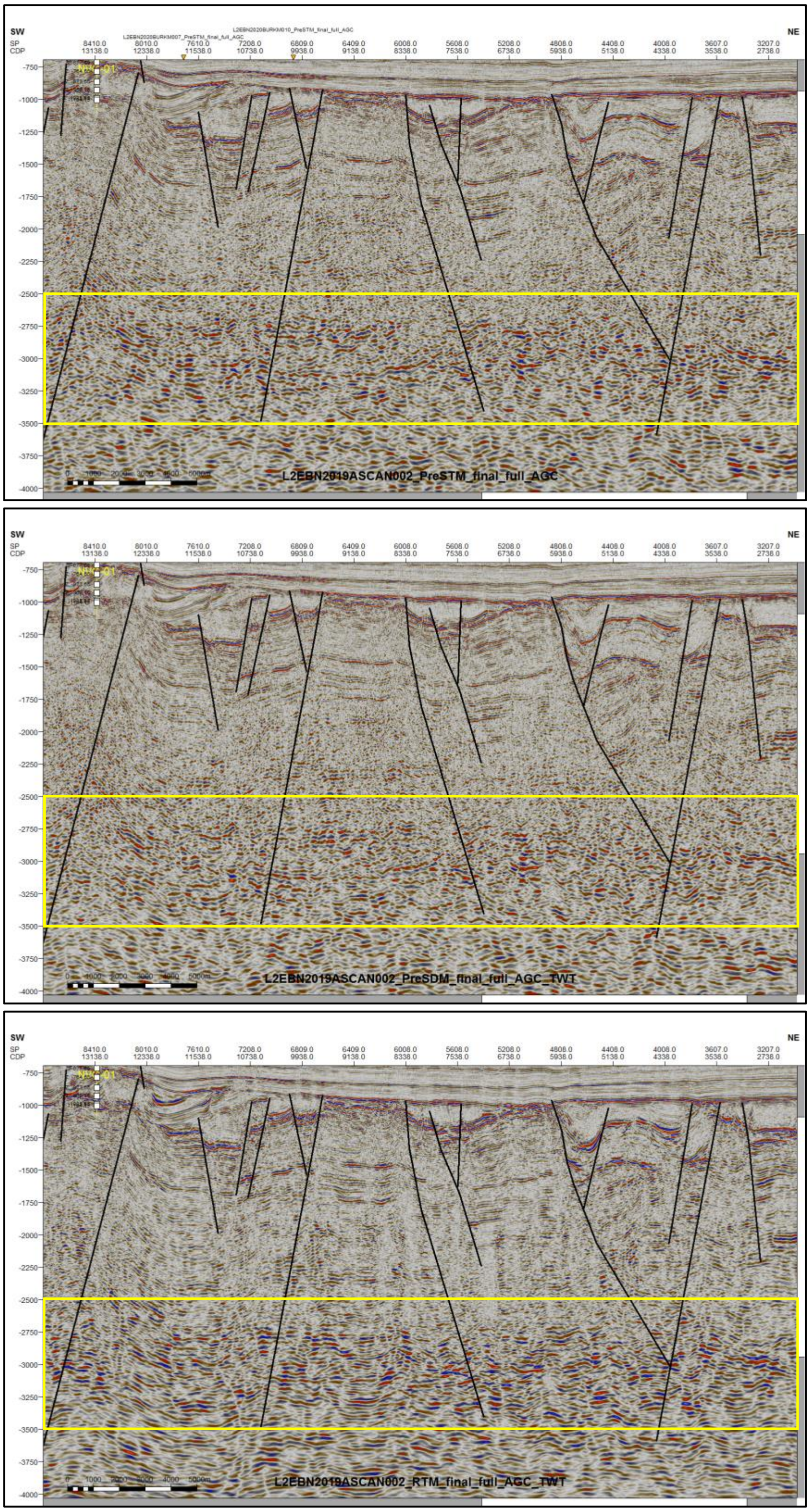

Figure 9 Comparison Dinantian interval in the Central Netherlands Basin part of section (TWT interval 2700–3100 ms). Note the improved continuity in this interval in the PreSDM/RTM sections; top PreSTM section, middle PreSDM section and bottom RTM section

Processing effort

The desired processing turnaround time for the SCAN PreSTMs is 4 months from the date the data has been delivered to DUG. For the first batch of lines this turned out to be too ambitious, mainly due to more elaborate parameter testing to establish a robust processing sequence and the fact that the first 9 lines were delivered as one batch, which allowed QC of intersections throughout the processing flow. Since then the turnaround time of 4 months has been achieved for most lines.

The PreSDM velocity model building, the final PreSDM & RTM migrations and full post-migration processing took an additional 4 months. Most of this time was spent on the PreSDM velocity model building and a total of 4 velocity iterations were performed, more than the initially planned 3 iterations.

Conclusions

Comparison between the three migration products shows that the differences between these products are limited. When considering the regional objectives of the SCAN program most of the changes and improvements seen in the PreSDM and RTM sections are not material. Only in the deeper part of the section, in the Limburg Group and the Dinantian, the improvements seen in the PreSDM and RTM sections become more relevant. In view of the considerable larger time effort needed for a PreSDM/RTM processing the choice to only perform a PreSTM processing of the SCAN lines is warranted. At this stage it is therefore recommended not to subject the other SCAN lines to a PreSDM processing workflow for the purposes of the regional SCAN campaign. For more detailed UDG exploration PreSDM processing of (part of) SCAN lines can be justified. Also, for well trajectory planning PreSDM may possibly be helpful in further constraining the location of important faults, depending on the local geology.

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