SCAN Special Seismic Products: 3D Cross-spreads and 2D Widelines

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2. Introduction

SCAN aims to assess geothermal potential on a regional scale in areas where seismic and well coverage is poor, by acquiring new seismic data and drilling data acquisition wells. Long 2D seismic lines were found to be the most cost-effective option to achieve the required improvement of seismic coverage. To plan the wells, a single 2D line is generally not sufficient; additional seismic data is required to image the third dimension. Planning the acquisition of the required additional seismic data results in a circular problem: additional data is required along the planned well trajectory, but to design the well trajectory, additional seismic data is required.

A common way to address this is to acquire a 3D seismic survey. A regular 3D seismic survey is very costly, however. This document describes two alternative seismic survey designs that were applied in the SCAN project: widelines; where a subsurface line is constructed in between two closely spaced parallel 2D lines by recording shot points on one line on the other and vice versa, and cross-spreads, which consist of two or more 2D lines crossing at oblique or right angles, where shots from one line are recorded on the other and vice versa.

3. Seismic Acquisition layouts

3.1. Cross-spread acquisition

In cross-spread acquisition the shots of a 2D seismic line are (also) recorded by the geophones on another 2D seismic line which intersects the first line (Figure 1). This acquisition process is reversed when shots of the second line are recorded by the geophones of the first line. By processing this data, a small pyramid-shaped 3D volume can be created around the intersection of the two lines (Figure 1). It must be noted that the fold of this 3D volume is very low and as such the quality of a cross-spread volume does not compare to a full 3D survey.

The SCAN cross-spreads were formed by recording two or more intersecting 2D lines that were positioned either orthogonally or obliquely, forming a 3D patch of midpoints (Figure 1). The first cross-spread acquisition was an opportunistic test over the intersection between the regional lines SCAN032 and SCAN033, in the West-Brabant Noord search area, near Steelhoven (Figure 2; Figure 3). In this particular cross-spread, a single source line (SCAN033) was recorded into an orthogonal single receiver line (SCAN032). The cross-spread was acquired to investigate the usefulness of the cross-spread type and evaluate if the resulting 3D image, though very low fold, can add value in the subsurface evaluation.

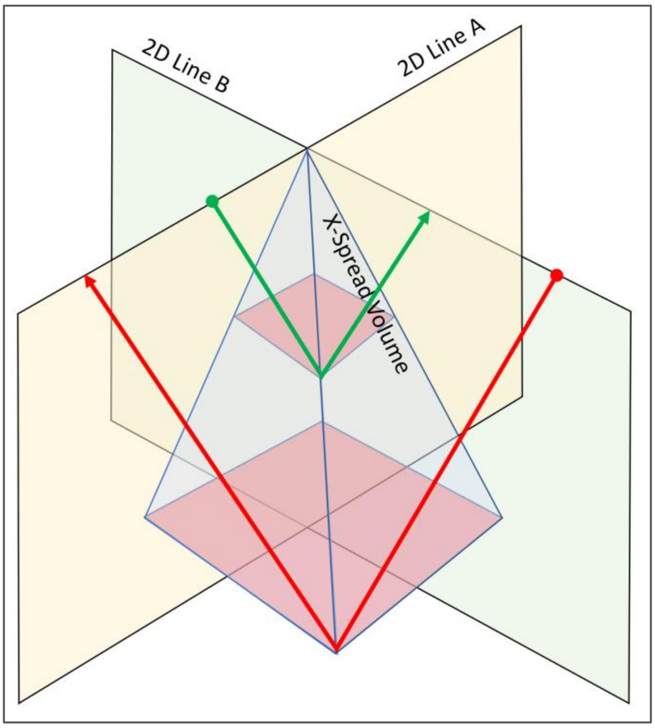

Figure 1 – Geometry of cross-spread acquisition for two perpendicular 2D lines. Shots (green ray paths) of Line A are recorded on Line B and vice-versa (red ray paths), resulting in a pyramidal shaped 3D volume (blue). The top of the pyramid is at the intersection of the two lines, the base of the pyramid is parallel to the 2D lines. Note that the shape of the 3D volume changes if more lines are included in the processing and/or if the lines do not intersect at a right angle.

Based on the successful test of cross-spread acquisition and processing for SCAN032/SCAN033, additional cross-spread acquisition became the standard for any local 2D seismic data acquisition for the SCAN well locations. To date, the SCAN project has acquired four different cross-spread scenarios, which are:

- A single source line recorded into an orthogonal single receiver line:
  - SCAN033 (shots) and SCAN032 (receivers)
- Two orthogonal/oblique lines recorded into each other (single cross-spread):
  - SCAN044 and SCAN045
  - SCAN053 and SCAN054
- Two parallel source lines recorded into a 3rd orthogonal line and vice-versa (double cross-spread):
  - SCAN046, SCAN047 and SCAN048
  - SCAN050, SCAN051 and SCAN052
- Two parallel source lines recorded into a 3rd orthogonal line and vice-versa, plus a 4th line of receivers only.
  - SCAN055, SCAN056 and SCAN057 and SCAN058 (receivers only)

The cross-spreads acquired to date are displayed in Figure 2 to Figure 8 and Table 1.

Search Area	Survey Name	Input 2D Lines	Area (in km^2) @ 1500ms
West Brabant Noord (Steelhoven)	L3EBN2021A	SCAN032 SCAN033	5,2
Ede-Veenendaal	L3EBN2021B	SCAN044 SCAN045	4,9
Deurne	L3EBN2022A	SCAN046 SCAN047 SCAN048	5,5
Utrecht Oost (Rijnwijck)	L3EBN2022B	SCAN053 SCAN054	4,5
Utrecht Oost (Vollenhove)	L3EBN2022C	SCAN050 SCAN051 SCAN053	4,1
Amstelland	L3EBN2022D	SCAN055 SCAN056 SCAN057 SCAN058	5,4

Table 1 – Processed cross-spreads (Status August 2023). The area indicated is the coverage of the cross-spread at 1500 milliseconds TWT.

In this report, a cross-spread of two orthogonal/oblique lines recorded into each other is called a single cross-spread, while a cross-spread with two parallel source lines recorded into a 3rd orthogonal line is called a double cross-spread, as the resulting 3D volume is a data merge of two single cross-spreads.

The acquisition of these cross-spreads during a conventional 2D rolling acquisition requires additional planning. Sufficient nodes should be available and detonation should be carefully monitored. The geophysicist on crew will also need additional time for downloading and preparing the field data. A decrease in production speed is therefore to be expected when compared to normal 2D acquisition. To mitigate against delays, the crew equipment setup can be designed to fit the acquisition.

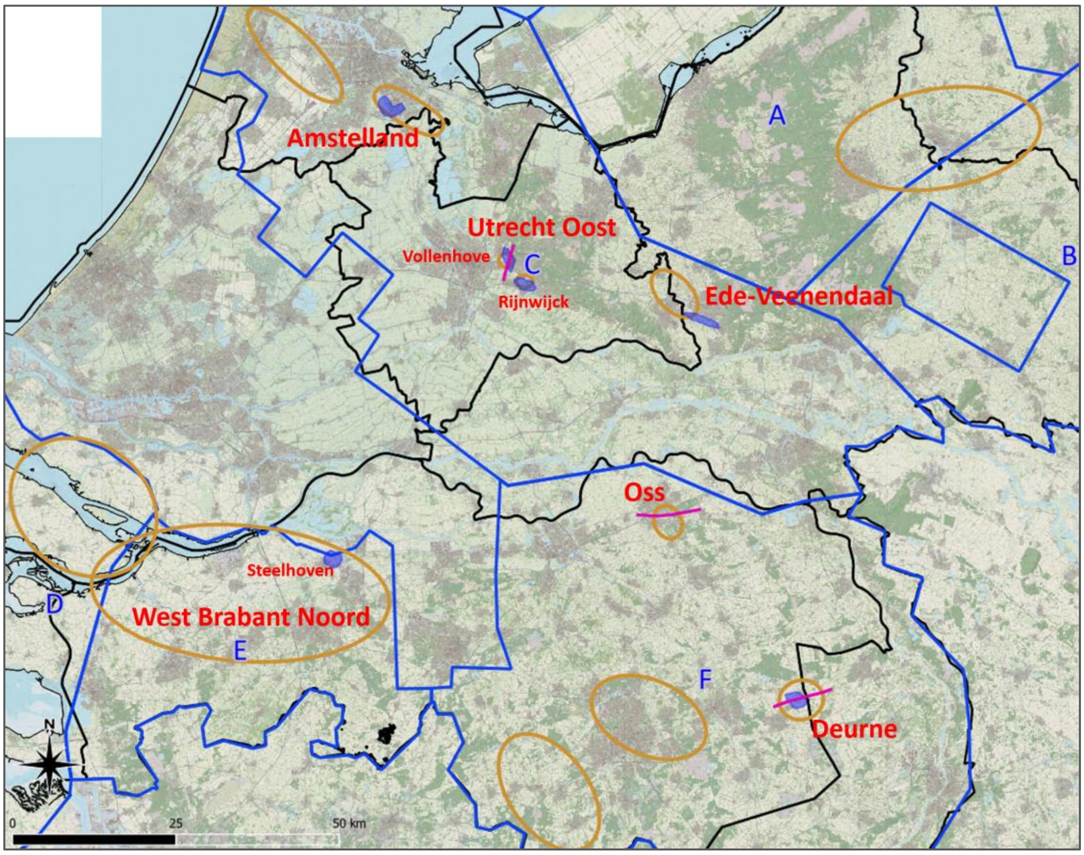

Figure 2 – Locations of the three widelines (pink lines), the six cross-spreads (blue polygons) and the SCAN Search Areas (brown ellipses). Status of available data in August 2023. Additional seismic acquisition is planned for Q3 2023 and additional cross-spreads will be acquired in search areas Ede-Veenendaal and Haarlem-Amsterdam-West.

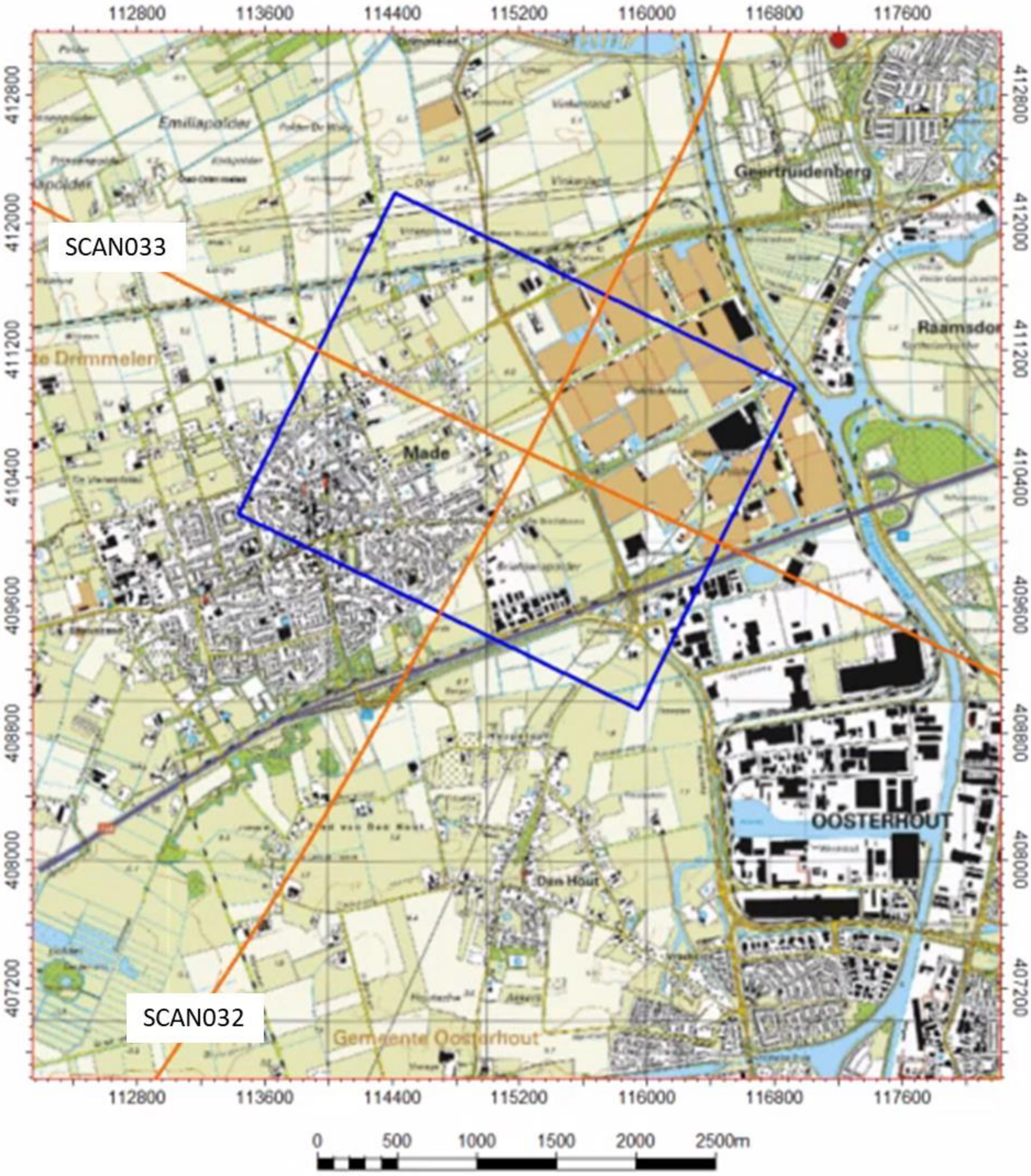

Figure 3 – Line location map showing the intersection for SCAN033_SCAN032_Xspread. The final stack outline for the cross-spread is shown as a blue polygon.

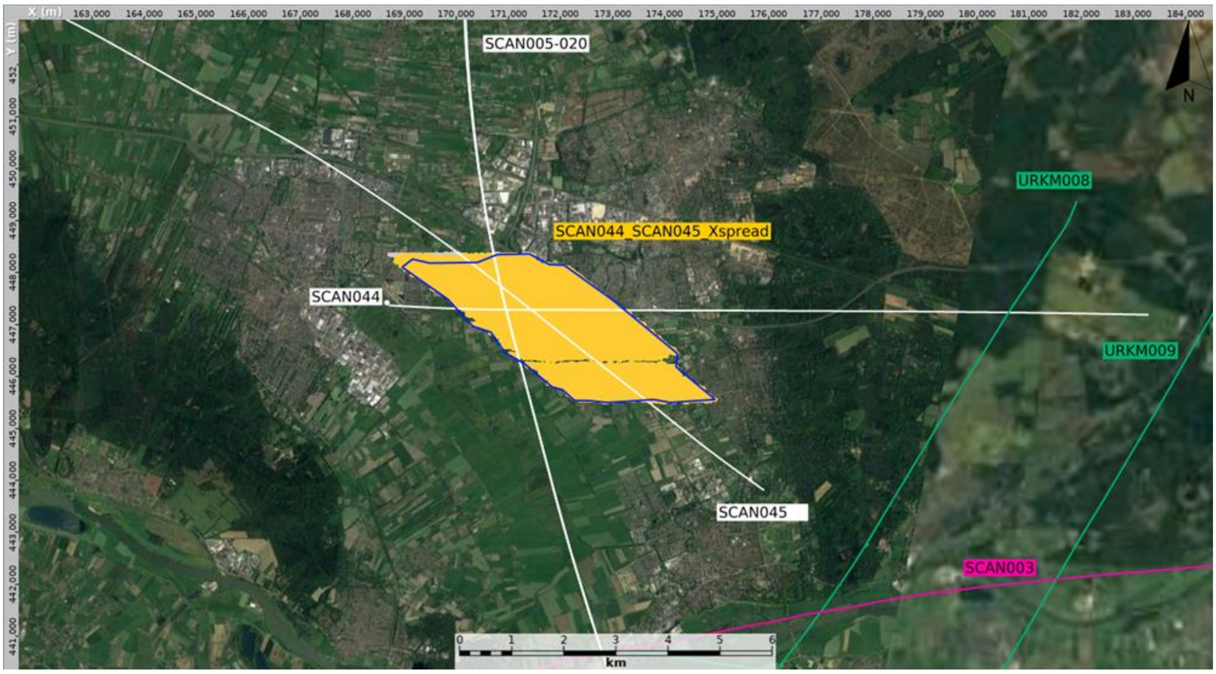

Figure 4 – Line location map showing the midpoints for SCAN044_SCAN045_Xspread. The final stack outline for the cross-spread is shown as a blue polygon.

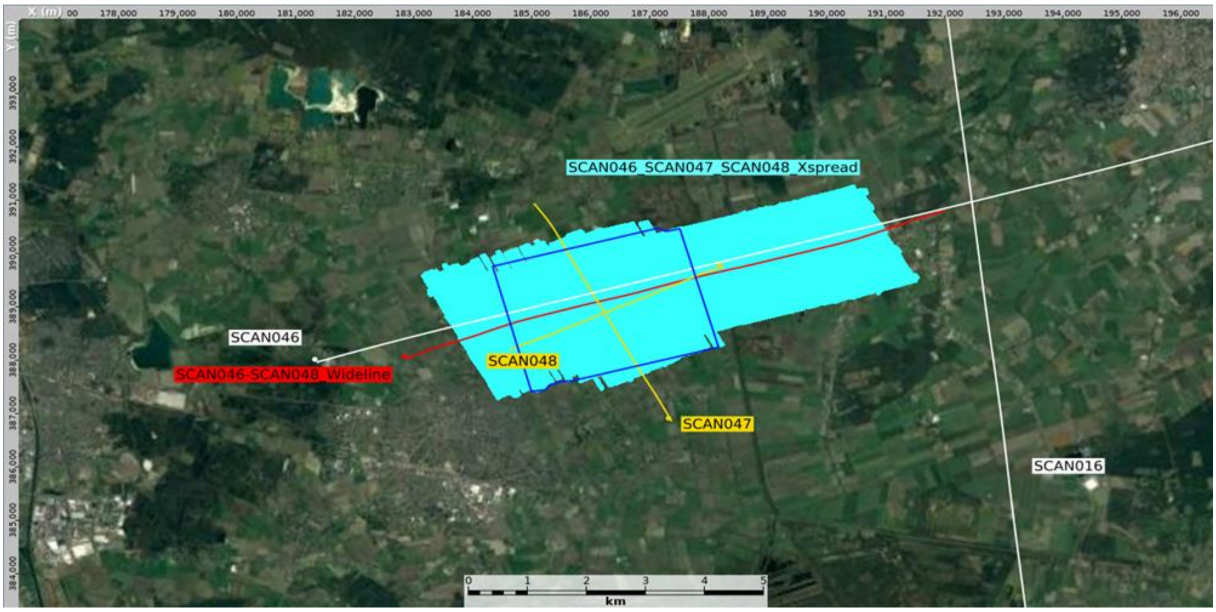

Figure 5 – Line location map of the Deurne area including a wideline composed of shots from SCAN046 into receivers on SCAN048 and vice versa, plus the midpoints from the cross-spread formed between SCAN046, SCAN047 and SCAN048. The final stack outline for the cross-spread is shown as a blue polygon.

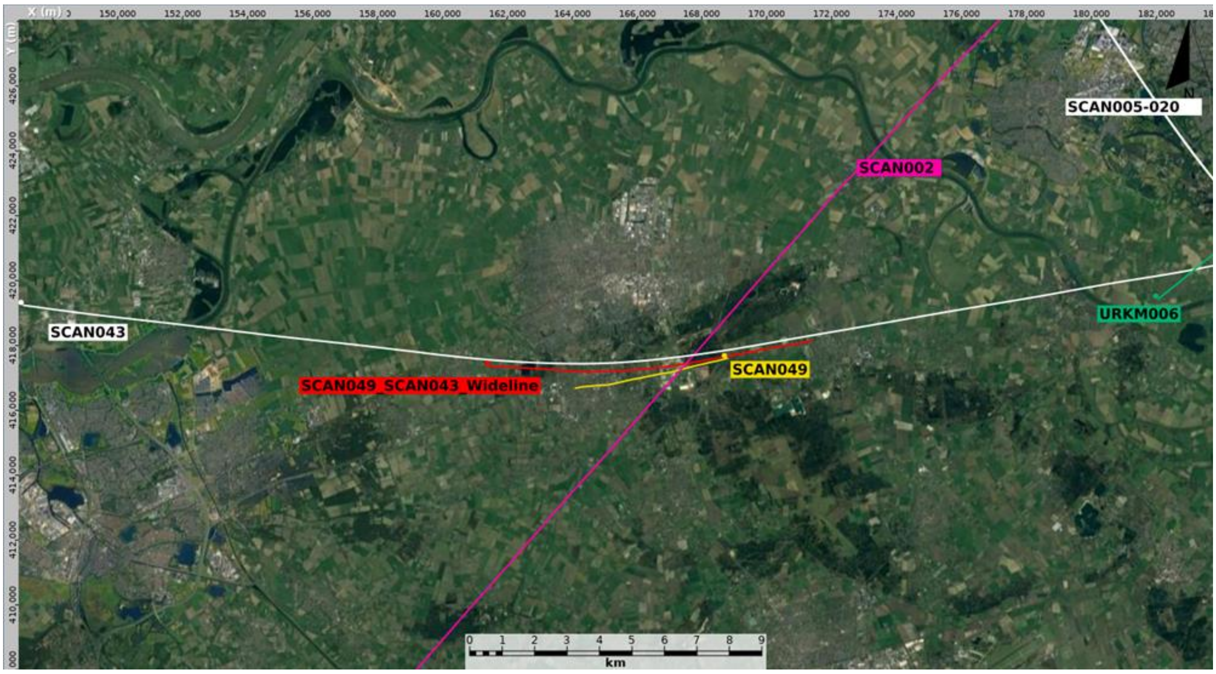

Figure 6 – Line location map of the Oss area with line SCAN049. This area includes a wideline, which was composed of shots from SCAN043 into receivers on SCAN049, and vice versa.

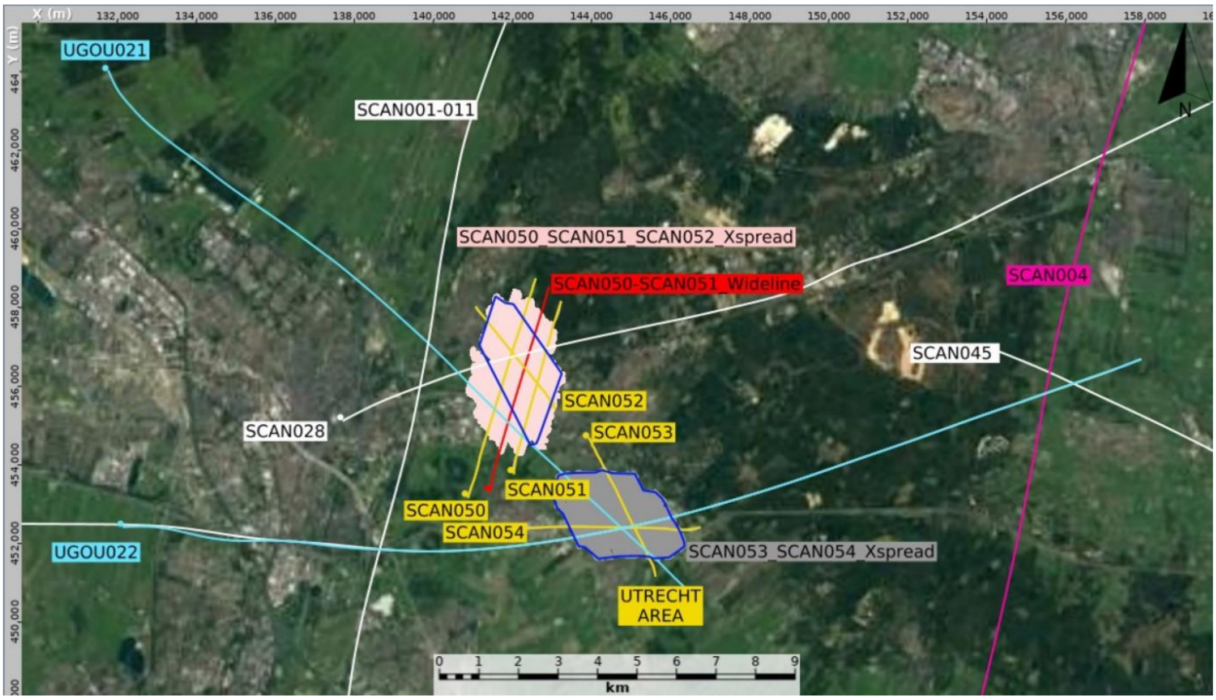

Figure 7 – Line location map of the Utrecht area including SCAN050_SCAN051_Wideline, plus the midpoints for SCAN050_SCAN051_SCAN052_Xspread and SCAN053_SCAN054_Xspread. The final stack outlines for the cross-spreads are shown as blue polygons.

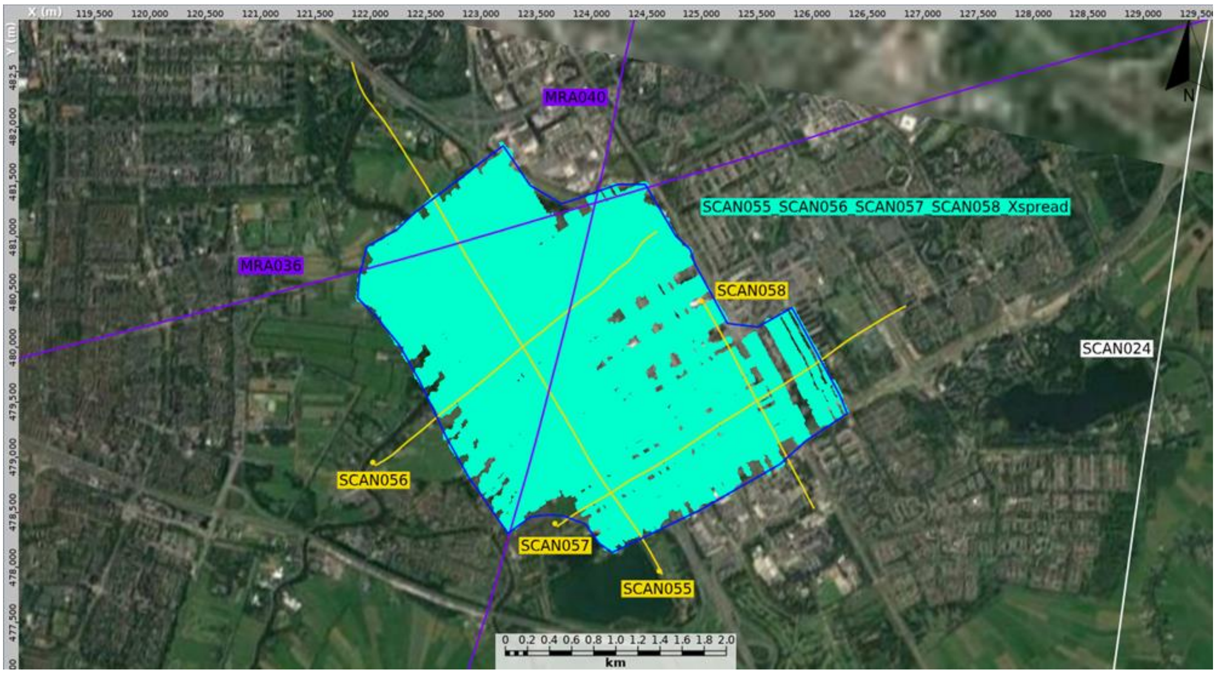

Figure 8 – Line location map of the Amstelland area with midpoints from the cross-spread formed between SCAN055, SCAN056, SCAN057 and SCAN058. The final stack outline for the cross-spread is shown as a blue polygon.

3.2. Wideline acquisition

In wideline acquisition the shots of a 2D seismic line are (also) recorded by the geophones of another nearby 2D seismic line which runs more or less parallel to the first line (Figure 9). This acquisition process is reversed when shots of the second line are recorded by the geophones of the first line, generating a concentration of midpoints in between the two lines (Figure 9). By processing this data, a subsurface line can be constructed approximately halfway between the two lines. As a result of this geometry, the shallowest part of the section has no coverage as reflections from this interval have a too high angle of incidence (Figure 9). The farther the input lines are apart, the less the shallow part of the section is imaged. The widelines acquired within the SCAN project to date are displayed in Figure 5 to Figure 7 and in Table 2.

Search Area	Line Name	Length (in km)
Oss	L2EBN2021ASCAN043_SCAN049_Wideline	9,5
Deurne	L2EBN2022ASCAN046_SCAN048_Wideline	8,9
Utrecht Oost	L2EBN2022ASCAN050_SCAN051_Wideline	5,4

Table 2 – Acquired SCAN widelines (Status August 2023). The input lines for the wideline are indicated in the line name.

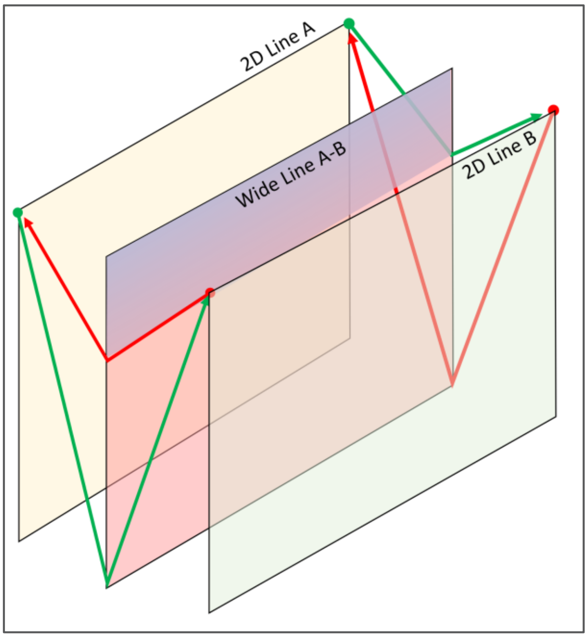

Figure 9 – Geometry of a wideline acquisition. Shots (green ray paths) of Line A are recorded on Line B and vice-versa (red ray paths), resulting is a new subsurface 2D line. Note there is no coverage of the shallowest part of the section due the too high angle of incidence.

3.3. Acquisition parameters

The 3D cross-spreads and 2D widelines were acquired using the same method and parameters as the longer regional lines (Table 3) and were consequently processed using the same broadband anisotropic pre-stack time migration processing sequence.

Acquisition parameters	
Receiver station interval	5 m
Source station interval	60 m
Sample rate	2.0 ms
Recording length	10000 ms
Source type	Explosives, shot hole
Receiver type	5 Hz geophone
Drilling type	Sonic
Drilling depth	Nominal 18 m, max 34 m, or till consolidated layer
Charge size	120 g – 1540 g

Table 3 – Acquisition parameters

4. Seismic Processing

4.1. 3D cross-spread processing sequence

Due to the low fold of the cross-spread data it was decided to process the cross-spread data using a Post Stack Time Migration (PostSTM) operator instead of the Pre-Stack Time Migration (PreSTM) operator used for the 2D lines. The basic PostSTM processing sequence for the cross-spreads followed the 2D PreSTM processing sequence as much as possible and is summarized below. Further details can be found in DUG's processing report[1].

Highlighted processes were reliant on the attributes extracted from the 2D production processing.

- Data reformat from SEGY to internal format
- Applied 3D geometry from sps
- Spherical divergence correction using T gain
- Geophone response correction
- Refraction static computation and application using delay-time solution from the full production 2D lines. No statics were derived on the cross-spread data
- Noise attenuation: 2D dip filter with wrap around AGC
- Noise attenuation: TFDN (2 passes)
- Noise attenuation: Despike
- Noise attenuation: Wavelet (D20) transform filter
- 1st pass surface consistent amplitude compensation:
  Source and receiver components from the full production 2D lines, except for SCAN058 which used a method based on an amplitude extracted from an NMO corrected receiver stack
- Inverse Q: Q=100 phase and amplitude using 40 Hz reference frequency and 12 dB gain stabilisation
- Surface consistent deconvolution: Source and receiver components from the full production 2D lines, except for SCAN058 which used a single operator for all receivers extracted from an average of all SCAN057 receiver operators
    - 160 ms operator length, 16 ms predictive gap, Design window: 200-3000 ms
- 1st pass velocity analysis: 1 km interval manual picks from the full production 2D lines interpolated/extrapolated to cover the 3D cross-spread area
- Noise attenuation: 2D dip filter with wrap around AGC
- Noise attenuation: TFDN (3 passes)
- 1st pass residual statics pass 1: Surface consistent MASTT algorithm applying source and receiver terms derived from the full production 2D lines
- 2nd pass velocity analysis: 1 km interval picked velocities from the full production 2D lines interpolated/extrapolated to cover the 3D cross-spread area
- 2nd pass residual statics pass 2: Surface consistent MASTT algorithm applying source and receiver terms from the full production 2D lines.
- 2nd pass surface consistent amplitude compensation: Source and receiver components from the full production 2D lines, except for SCAN058 which used a single operator for all receivers extracted from an average of all SCAN057 receiver operators
- AGC products only: 500 ms AGC

[1] sCAnPr_007_009_LocalSeismicProcessingReport_230313

- Stack: 1/N for true amplitude stacks (1/√N for AGC stacks) to account for mis-binned traces resulting from irregular source and receiver positioning during acquisition
- Static to shift to final datum
- TA products only: TFDN noise attenuation
- 3D regularisation (210 m inline/crossline half window size). An additional interpolation step was required for SCAN055_SCAN056_SCAN057_SCAN058_Xspread
- TA products only: 3D Cadzow rank-reduction noise attenuation
- TA products only: TFDN noise attenuation
- Noise attenuation: FKK dip filter
- AGC products only for SCAN044_SCAN045_Xspread: TFDN noise attenuation
- Static to shift back to floating datum
- Remove spherical divergence correction using T gain
- Trace removal to restrict noisy edge traces using spatial polygons (SCAN046_SCAN047_SCAN048_Xspread and SCAN050_SCAN051_SCAN052_Xspread only)
- Migration: Post-stack anisotropic VTI Kirchhoff using PreSTM velocities from 2D lines
- Eta = 0, 1.4 km aperture length, time-variant dip
- Conversion to zero phase: Statistically derived filter operator
- Static to shift to final datum
- Noise attenuation: 3D Cadzow rank-reduction noise attenuation
- Spectral broadening
- Time-variant frequency domain filter
- Trace removal to restrict noisy edge traces using spatial polygon (SCAN050_SCAN051_SCAN052_Xspread only)
- AGC products only: Dual gate 500/2000 ms AGC
- TA products only: T0.75

The cross-spread approach utilized existing data acquired for the 2D lines to create a new set of midpoints, which in the case of the orthogonal/oblique 2D lines, formed a 3D patch of midpoints that were able to benefit from 3D processing algorithms.

A 3D binning scheme based on the acquisition template was imposed on the midpoints and resulted in a grid of low fold CDP bins. The low fold unfortunately negated any CDP gather processing as well as velocity picking, so once the shot/receiver processing was complete, the next step was to proceed directly to stack, followed by a post-stack Kirchhoff migration.

The nature of the acquisition also meant that as well as low fold CDPs, there were a lot of empty CDP bins, but these were successfully infilled using 3D regularization. The resulting regularized volumes were better suited for both post-stack migration and also the Cadzow rank-reduction noise attenuation. Along with the regularized volumes, pre-regularization volumes were generated to allow the interpreter to distinguish between seismic events and regularization artefacts.

Probably the most significant restriction from the cross-spread workflow was the inability to apply demultiple techniques, including Radon demultiple and the power of stack. However, extensive noise attenuation and careful restriction of traces input to the migration mitigated this and reduced the impact of any remaining multiple.

The resulting stacks are mini 3D volumes that can aid interpretation. There were also remarkably good ties when compared against the final PreSTM stacks of the constituent 2D lines.

4.2. 2D wideline processing sequence

The widelines were processed using the same fundamental PreSTM processing sequence as the regional 2D lines as much as possible, which is summarized as follows. Further details can be found in DUG's processing report[1].

- Data reformat from SEGY to internal format
- Applied crooked line geometry
- Edits: Remove traces zeroed in the field
- Spherical divergence correction
- Geophone response correction
- Refraction static computation and application using delay-time solution
- Noise attenuation: +/-1250 m/s Weiner dip filter
- Noise attenuation: Despike
- Noise attenuation: Wavelet (D20) transform filter
- 1st pass surface consistent amplitude compensation
- Noise attenuation: TFDN
- Inverse Q: Q=100 phase and amplitude using 40 Hz reference frequency and 12 dB gain stabilisation
- Surface consistent deconvolution: source and receiver
- 160 ms operator length, 16 ms predictive gap, design window: 200-3000 ms
- 1st pass velocity analysis: 1 km interval manual picks
- Noise attenuation: 1.75 ms/tr (2857 m/s) dip filter and wavelet transform filter on shots
- Noise Attenuation: TFDN on CDPs and WTF on noise cone
- 1st pass residual statics pass 1
- 2nd pass velocity analysis: 500 m interval picked velocities
- 2nd pass residual statics pass 2:
- 2nd pass surface consistent amplitude compensation
- ADDITIONAL Noise Attenuation for SCAN047, SCAN055, SCAN056 and SCAN057: Dip filter on shots with NMO applied
- Spherical divergence removed: T
- Low cut filter: 2.5 Hz with 18 dB/Octave slope
- Migration (PreSTM 1):
  Isotropic 4th order curved-ray Kirchhoff using 2km smoothed stacking velocities.
- Velocity analysis:
  500 m manually picked 2nd order velocities with automatic Eta picking every 250 m
- Migration (PreSTM 2):
  Anisotropic VTI Kirchhoff using re-picked 2nd order velocities and auto-picked Eta
- Time-tomography: Automatic non-parabolic RMO picking every 250 m followed by time-tomography to update velocity and Eta simultaneously and the results smoothed.
- AGC products only: 2000 ms AGC
- Migration (PreSTM 3):
  Anisotropic VTI Kirchhoff using re-picked 2nd order velocities
- Auto-picked Eta, 60 m offset bins to 6990 m, 3 km aperture length, time-variant dip
- Demultiple: Radon domain
- Noise attenuation: Weiner dip filter with signal protection

[1] sCAnPr_007_009_LocalSeismicProcessingReport_230313

- Trim statics: 12 ms maximum shift, smoothed field
- Noise attenuation: CDP offset Cadzow rank-reduction random noise attenuation
- Noise attenuation: Common offset dip filter
- Drop offsets not input to migration
- Mute: Offset domain manually picked inside and outside trace mutes
- Conversion to zero phase: Statistically derived filter operator
- AGC products only: 2000 ms AGC
- Stack: 1/N for true amplitude stacks (1/√N for AGC stacks)
- Spectral broadening
- Noise attenuation: Weiner post-stack time variant dip filter
- Noise attenuation: Cadzow rank-reduction noise attenuation
- Noise attenuation: Structurally Oriented Filter (SOF)
- Time-variant frequency domain filter
- AGC products only: Dual gate 500/2000 ms AGC
- True amplitude products only: Bulk line scalar
- Final datum shift

Please note that there were some other more minor variations in parameters and additional noise attenuation for some of the lines, which is mentioned in the full processing report.

The widelines acquired by shooting parallel lines at the same time with all shots into both sets of receivers was a highly cost-effective method for acquiring additional seismic. However, there are some limitations of the widelines – large spacing between the lines means that the migration is not as effective (rays do not sample the same geology). Re-projecting the shot and receiver co-ordinates for the parallel lines was effective for SCAN050_SCAN051_Wideline, which had the largest line separation of 840 m, but could not be applied to the other widelines as they had a more crooked geometry. The widelines also had limited near offsets, and therefore poor fold in the shallow.

4.3. Processing effort

Given the experience of the regional SCAN 2D processing, which had a desired processing turnaround time of four months for each 2D line, the processing effort for the 2D widelines was planned to take five working weeks. For the 3D cross-spread processing the processing effort was estimated to be 3 weeks for a simple cross-spread and four weeks for the more complex double cross-spreads.

However, during most of the processing period the processing contractor (DUG) carried out work in parallel on the several local 2D lines, the widelines and also on the cross-spreads, so the average elapse turn-around time for the individual data sets was as follows:

- 2D widelines: 3,7 months (3 widelines)
- 3D cross-spreads: 3,5 months (6 cross-spreads)

5. Results

In this section the wideline and cross-spread deliverables are analysed. All displayed seismic data follows the EBN polarity convention as displayed in Figure 10. These sections are in TWT and are final full stack sections with AGC (Automatic Gain Control) applied. The widelines and other 2D sections are migrated with a PreSTM migration operator, whereas the cross-spreads have a PostSTM applied.

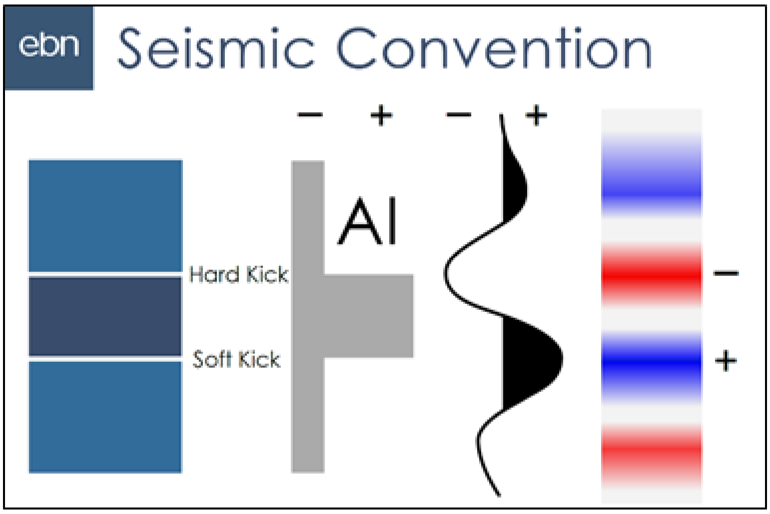

Figure 10 – Seismic convention used

All the examples shown in this section originate from the Vollenhove area in the Utrecht Oost search area (Figure 2), unless otherwise indicated. The results of the other widelines and cross-spreads are quite comparable to the Vollenhove example. On some of the seismic sections horizon interpretations are displayed. The colour coding of these horizons is shown in Table 4. The colours of the interpreted faults are consistent in all the figures.

Base Lower North Sea Gp.	
Base Rijnland Gp.	
Base Lower Germanic Trias Gp.	

Table 4 – Horizons interpreted on seismic sections

5.1. Results cross-spreads

Six cross-spread volumes have been processed (Figure 2 and Table 1). For the cross-spreads the following products were delivered in Two Way Time (TWT).

- Final PostSTM volume, with and without AGC scaling
- RMS migration velocity volume
- Raw stack and pre-migration volumes, with and without AGC scaling
- Pre-regularization volume, with AGC scaling applied

A complete list of processing products can be found in DUG's processing report[1].

Since some interpolation is needed for the generation of the final volumes the pre-regularization volume can be used to get an impression of the real coverage of the pre-processing data. These pre-regularization volumes were in fact used as the foundation of the interpretation, in order not to mis-interpret artefacts caused by regularization as actual seismic events. If the input lines do not intersect perpendicularly the shape of the resulting cross-spread will be elongated (Figure 4). If several line crossings are close to each other a single larger cross-spread volume can be processed (Figure 12).

In Figure 11 a comparison is made between a recently acquired 2D section (but not part of the cross-spread processing) and a line extracted from the cross-spread volume overlapping this line. Obviously the cross-spread only covers a very small part of the (much longer) 2D section. In most of the cross-spread section the important horizons and faults can be picked with confidence. The continuity of the reflectors is less than in the 2D section. The main difference can be seen in the fault block west (left) of the brown fault. Here there may not be enough data to properly migrate the reflectors to the correct position. Imaging below approximately 1 s TWT is not as good as the 2D line as a result of the low fold of the data and potentially the lack of long offsets for these short lines. The limited data coverage at the edges of the cross-spread volumes can result in small to large migration swings at the data edges. It is important to note this and not to overinterpret these seeming upward curving "reflections".

[1] sCAnPr_007_009_LocalSeismicProcessingReport_230313

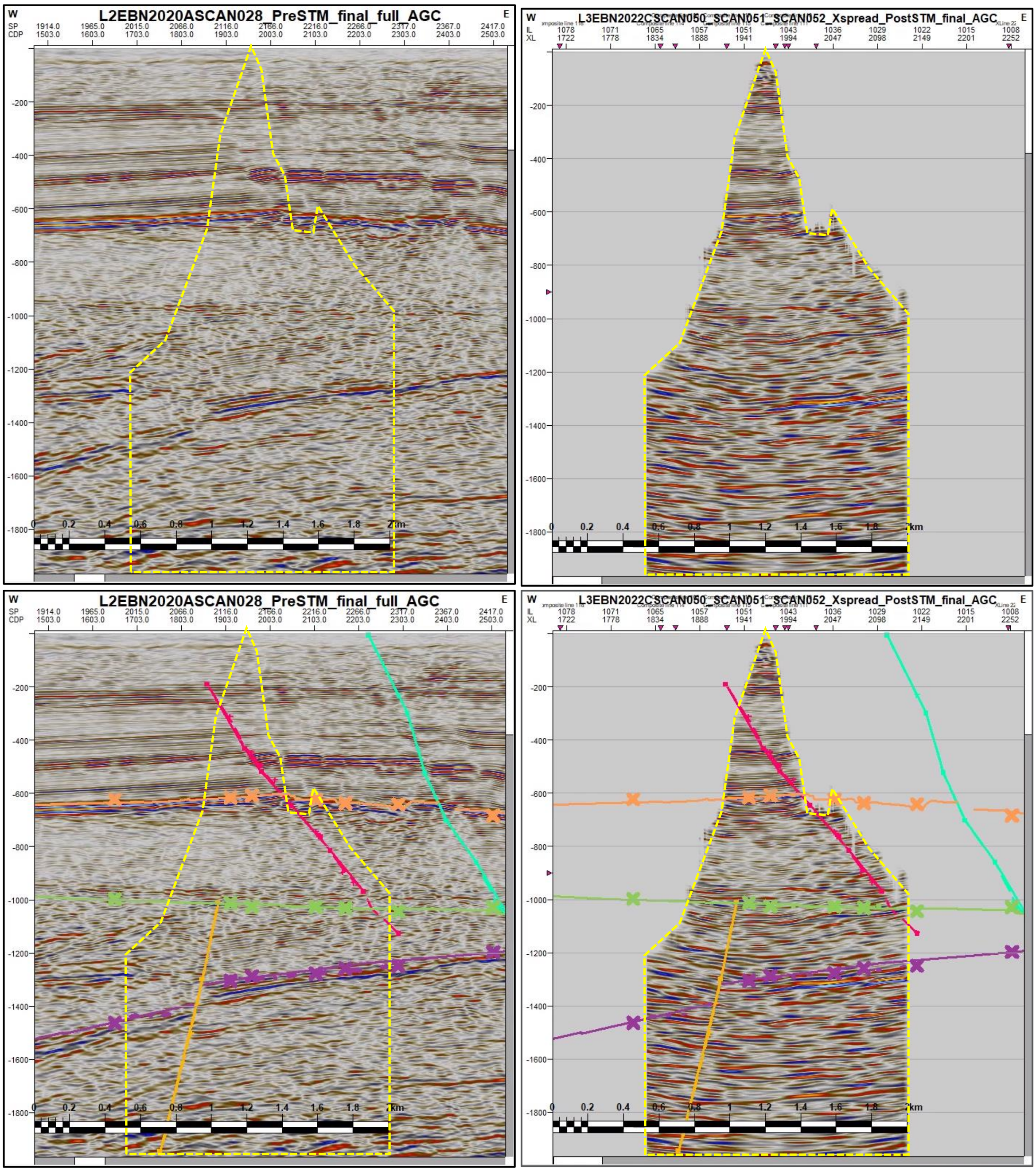

Figure 11 –Seismic 2D section (TWT) SCAN028 (left, only relevant part shown) compared with a line extracted from the cross-spread volume Utrecht Oost (right) overlapping this line, both with and without interpretation. Line SCAN028 did not provide input to the cross-spread, as it was acquired in an earlier stage. Location of the line see Figure 13.

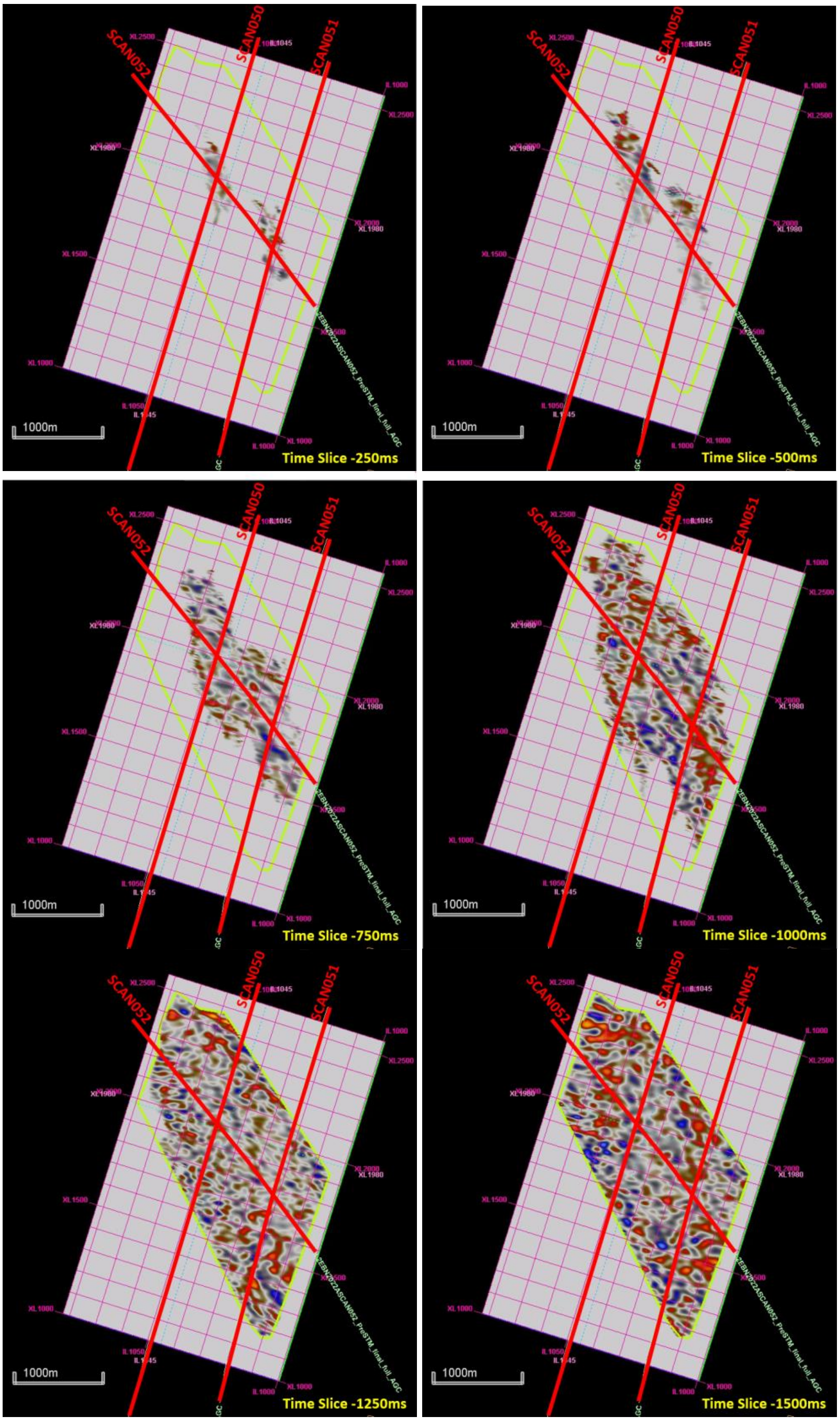

Figure 12 – Six time slices of the L3EBN2022C cross-spread (Utrecht Oost, Vollenhove). Note the deviation of the coverage from the ideal pyramid shape due the oblique intersections and the use of two line crossings from input line SCAN050, SCAN051 and SCAN052

In Figure 13 a comparison has been made between an interpretation based on only 2D seismic lines (including one wideline and several vintage lines) and an interpretation including the cross-spread volume. The inclusion of the cross-spread results in a much denser interpretation (here in a 125-150m grid). The position of the brown fault can be determined in more detail, while also the gridding of the mapped horizon is much more controlled than it would be when only 2D input data is available. Moreover, and perhaps the main benefit of having the cross-spread available, faults identified on the separate 2D lines can be correlated between lines with higher confidence than would be the case if only 2D data would be available.

To demonstrate the usefulness of the cross-spread three hypothetical deviated wells are displayed in the cross-spread (Figure 13). If only 2D data is available the planning of such wells carries some uncertainties, as the projections of the wells on the 2D sections does not show the actual intersections of the wells with the geology (Figure 14). Using seismic sections from the cross-spread parallel to the deviated well tracks gives a more certainty on the positioning of the planned wells with respect to the main faults (Figure 15 and Figure 16).

With a cross-spread volume and the interpretation of the faults and horizons herein a more detailed structural model can be made of the subsurface. Deviated wells can be planned in 3D with more certainty (Figure 16). For a real well planning case it is recommended to convert the seismic TWT data to depth.

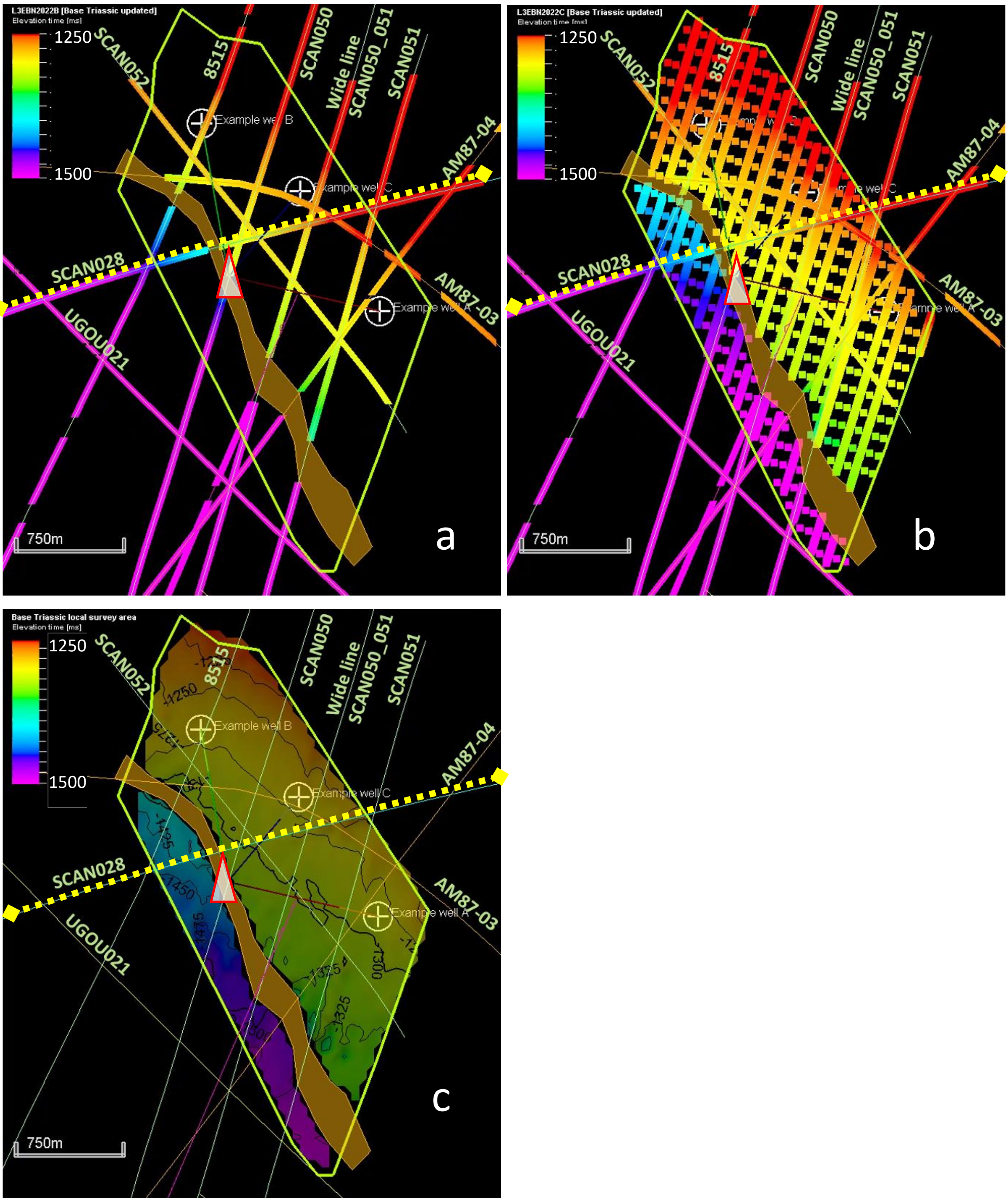

Figure 13 – Seismic interpretation (TWT) of Base Lower Germanic Trias of the L3EBN2022C cross-spread (Utrecht Oost, Vollenhove). Three hypothetical example wells are indicated (A in red, B in green and C in blue colour) Surface location indicated by a red triangle. Figure a: the picking on the 2D seismic lines and the wideline. Figure b: includes the picking on the cross-spread with an interpretation grid of 150m (every 5th inline) and 125m (every 50th crossline). Figure c: TWT grid including fault gap determined from the cross-spread interpretation (brown fault)

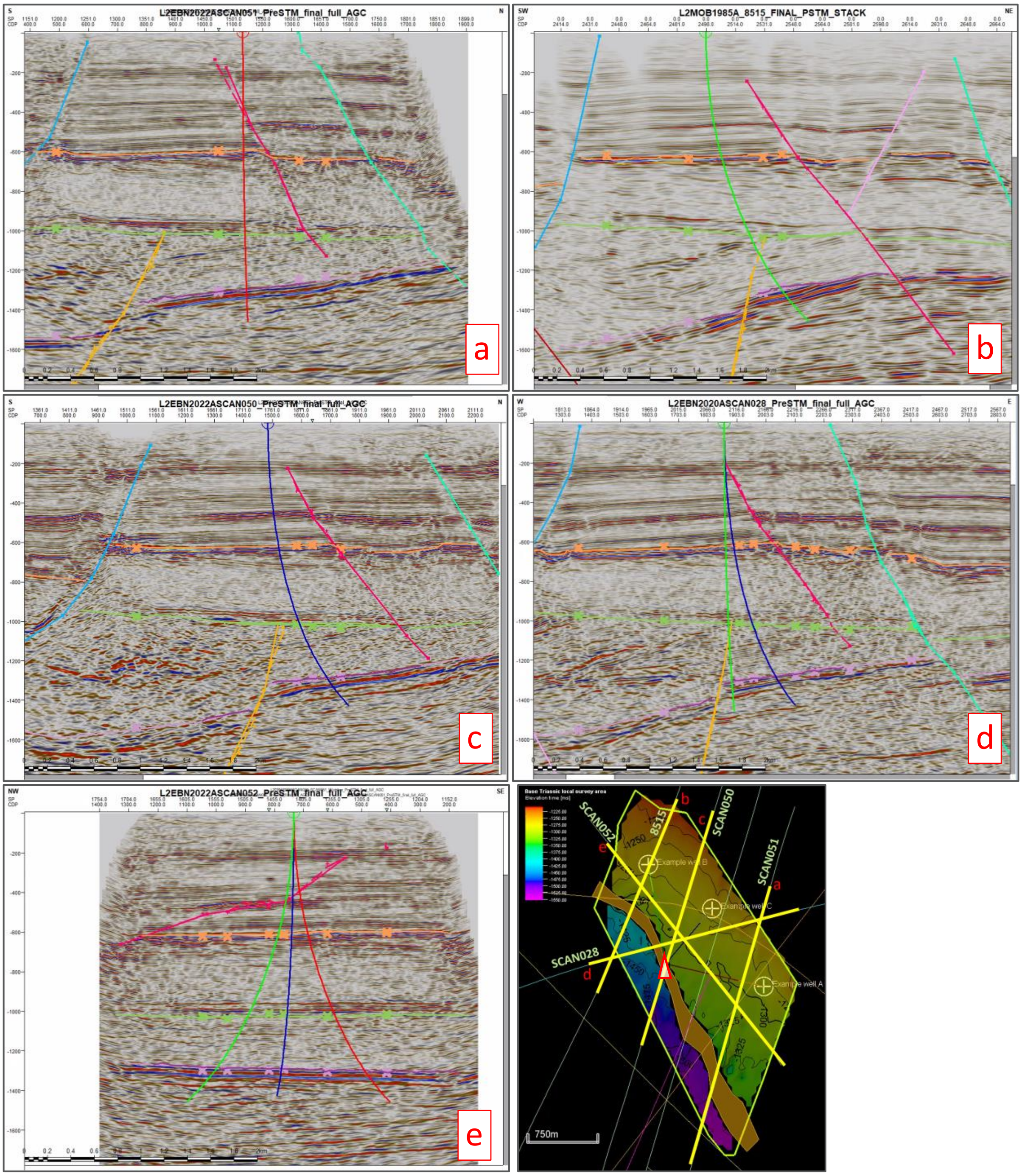

Figure 14 – Seismic interpretation (TWT) of five 2D seismic sections in the area Utrecht Oost (Vollenhove). Three hypothetical example wells are included (A in red, B in green and C in blue colour, surface location in red triangle) and projected on the sections. Note the uncertainty on these 2D sections whether or not the projected wells intersect with the red or brown faults

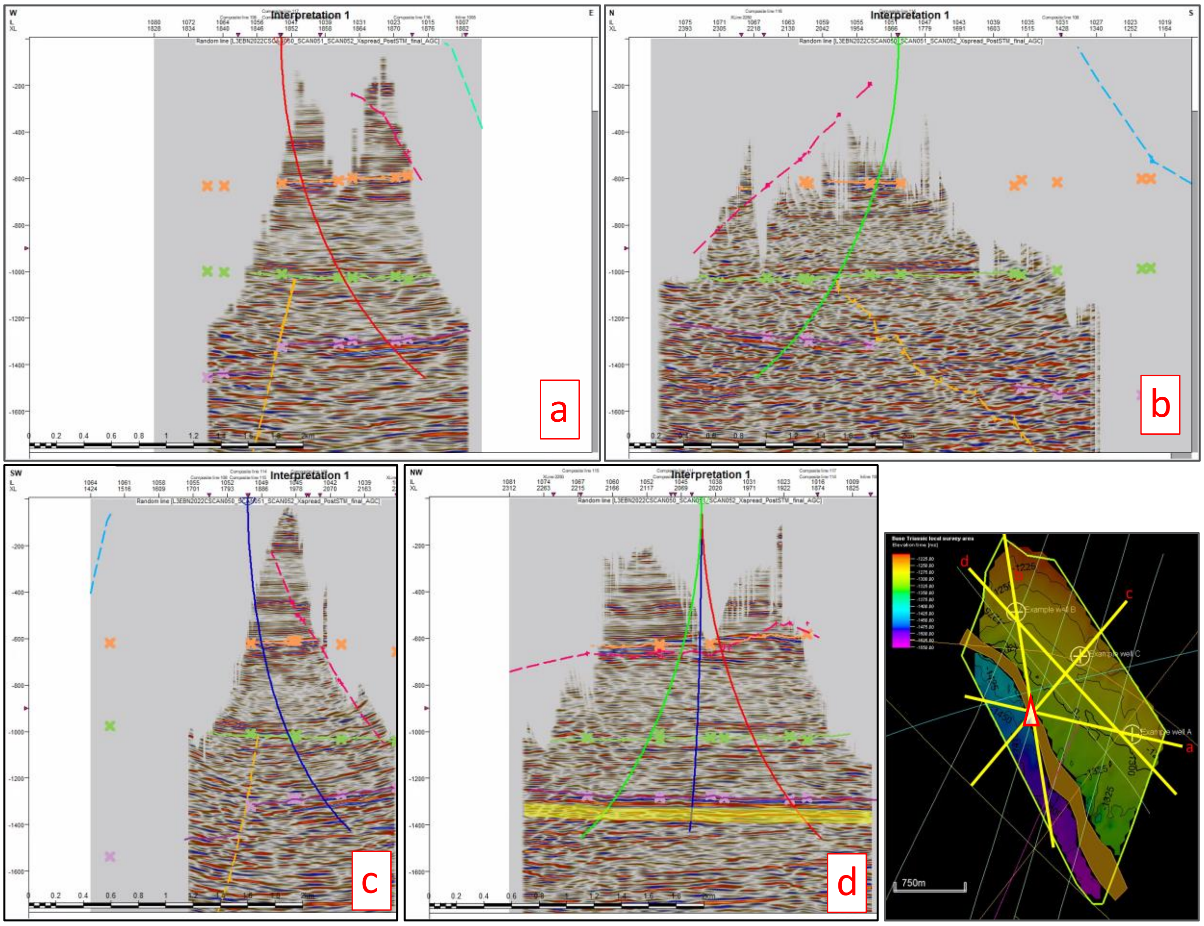

Figure 15 – Seismic interpretation (TWT) of four arbitrary lines through the cross-spread volume in the Utrecht Oost (Vollenhove) area. Sections a to c follow well paths of the three hypothetical example wells (A in red, B in green and C in blue colour, surface location in red triangle), while figure d shows the well intersections near the Rotliegend reservoir target (yellow shading). Note that well tracks A and C clearly do not intersect the red and brown faults, while well track B may just intersect the brown fault (section b)

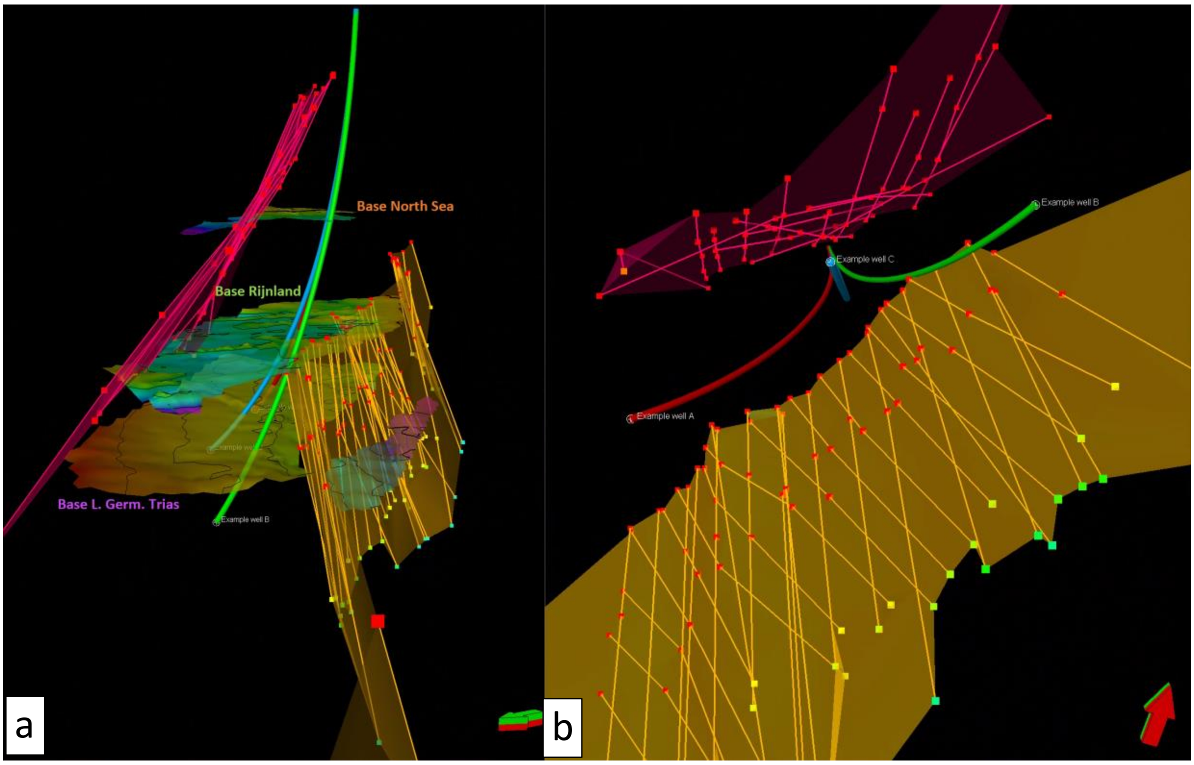

Figure 16 – a: 3D view (looking SE) of the red and brown fault planes, the TWT grids in the cross-spread volume and three hypothetical example wells (A in red, B in green and C in blue colour) Scale: the horizontal distance between the red and brown fault at Base Rijnland level is around 750 m, while the vertical depth of the wells is around 1450 m. Figure b shows the wells and faults from below. Note that the fault sticks of the brown fault plane shows that it is well defined. Well B may just intersect the brown fault. Scale: the distance between TD of example wells A and B is around 1.7 km.

5.2. Results widelines

Three widelines have been processed (Table 2; Figure 2). For the widelines the same processing products were delivered in TWT as for normal 2D PreSTM lines:

- Final near/mid/far & full PreSTM sections, with and without AGC scaling
- RMS stacking velocities
- RMS migration velocities and the Eta field
- Associated raw stacks and pre-stack gathers

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

As explained in section 3.2, the shallowest part of a wideline section has no coverage and the farther the input lines are apart the less the shallow part of the section is imaged. This effect is displayed in Figure 17 where the input lines are not parallel, resulting in a decreased coverage where the lines are farther apart. The offset stack sections are off course also influenced by the increased offset between shot and geophones in wideline acquisition. The near offset sections have an even lower coverage in the shallow part of the section.

The widelines are helpful in the 2D mapping of an area as they provide an additional subsurface line, which provides more certainty in the correlation of faults between the 2D sections (Figure 18 and Figure 19). In the Utrecht Oost wideline (Figure 19) the continuity of the reflectors is less than in the input sections (Lines SCAN050 and SCAN051). This is probably due to the more complicated ray paths, which makes correct positioning of the data more uncertain.

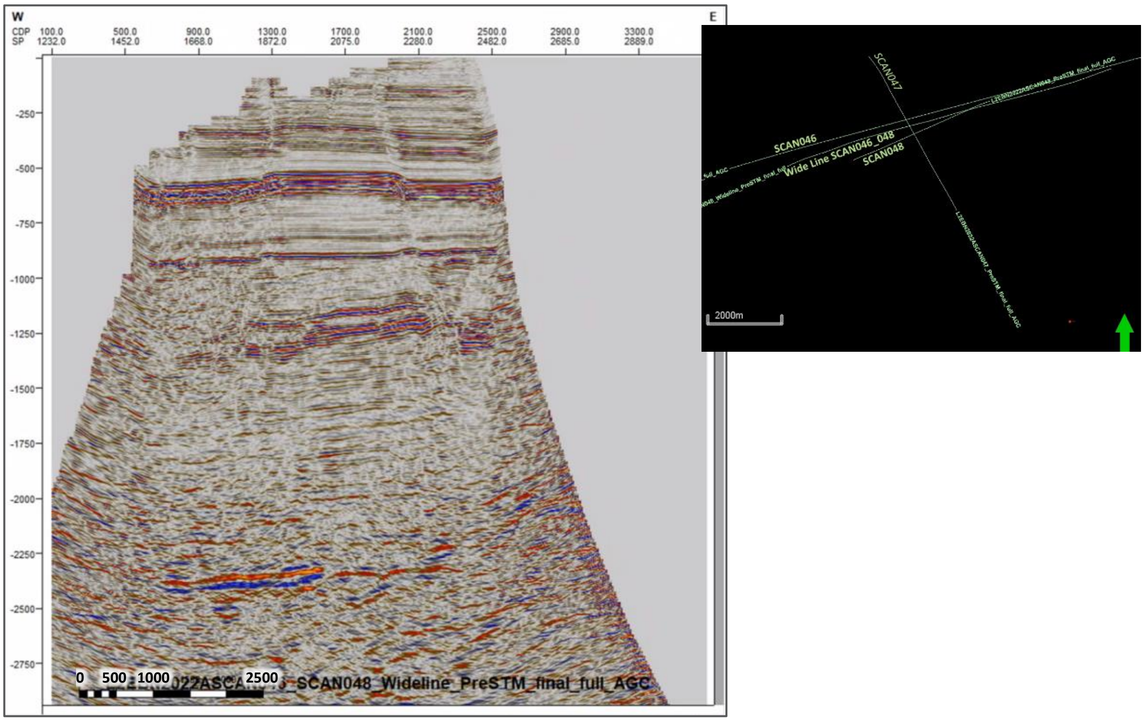

Figure 17 – SCAN wideline SCAN046_SCAN048 (Deurne search area). The distance between lines SCAN046 and SCAN048 increases from 100m in the east to 700m in the west of the line resulting in decreasing coverage of the upper part of the section in the western part of the line

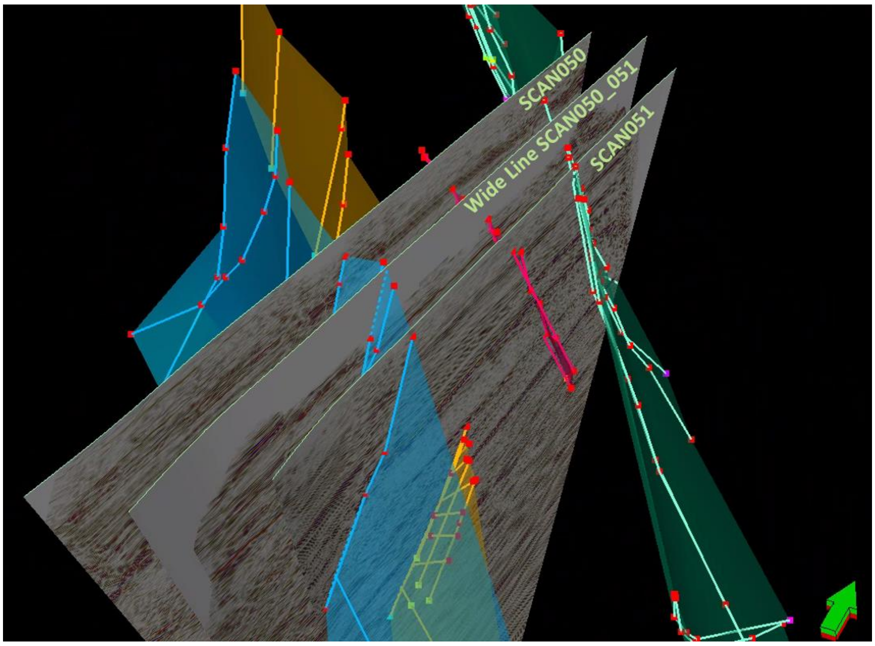

Figure 18 – 3-D View of lines SCAN050 and SCAN051 and processed wideline SCAN050_051 (Utrecht Oost, Vollenhove). The distance between lines SCAN050 and SCAN051 is approximately 800 m. The main fault planes have been displayed

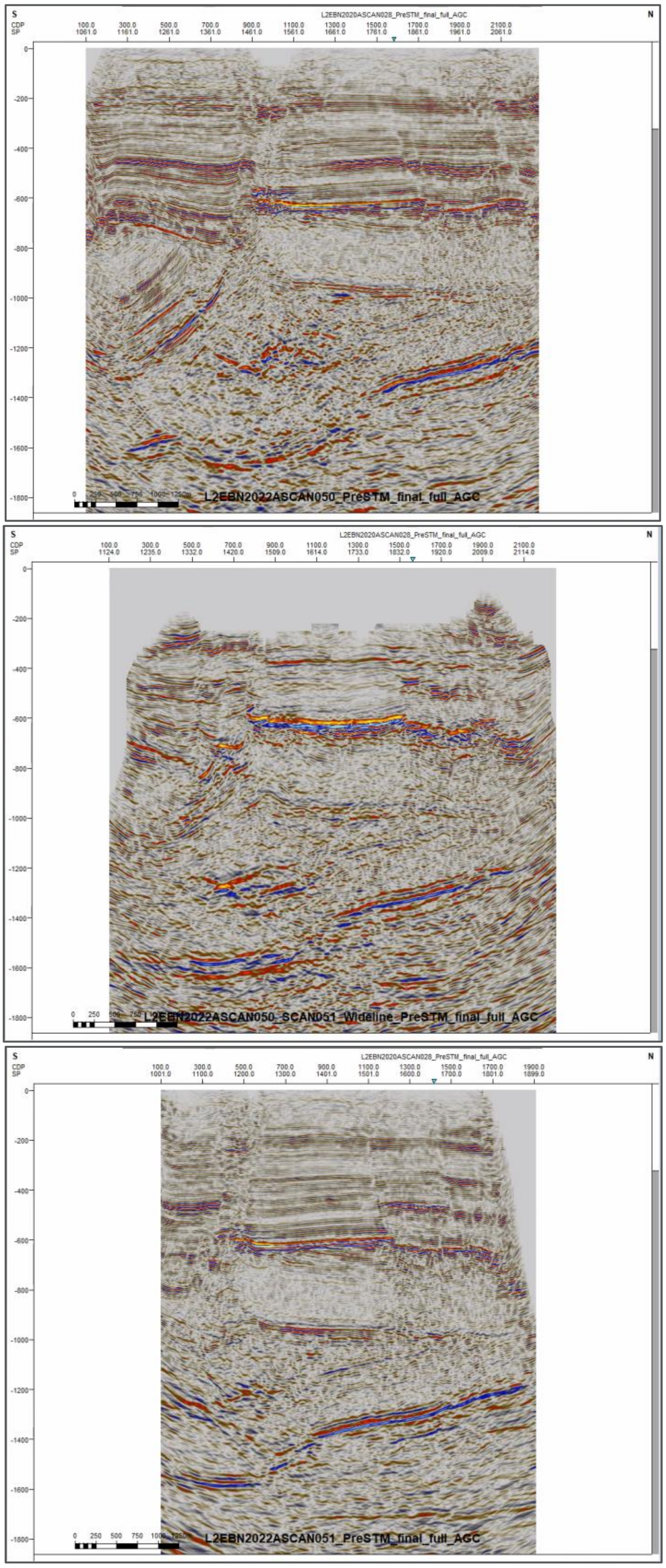

Figure 19 – 2D lines SCAN050 (top) and SCAN051 (bottom) and processed wideline SCAN050_051 (middle) (Utrecht Oost, Vollenhove). The distance between lines SCAN050 and SCAN051 is approximately 800 m.

6. Conclusions

This document describes two alternative seismic survey designs that were applied in the SCAN project: widelines; where a subsurface line is constructed in between two closely spaced parallel 2D lines by recording shot points from one line into the other and vice versa, and cross-spreads, which consist of two or more 2D lines crossing at oblique or right angles, where shots from one line are recorded on the other and vice versa.

Cross-spread surveys are not intended to be full-fledged 3D-surveys nor should they be used as such. Cross-spreads are primarily intended to offer guidance in correlating faults between separate 2D lines with higher confidence. An evaluation of cross-spread acquisition results show that these limited aims were achieved.

Widelines and cross-spreads were thus found to be an acquisition method that provided the required data for the SCAN project at a significantly lower cost than a full-fledged 3D acquisition or a high density 2D grid. It is therefore concluded that projects with aims similar to SCAN may benefit from cross-spread and wideline acquisition designs.
When assessing the suitability of wideline and cross-spread acquisition designs for other projects such as conventional geothermal projects it should be realized that the requirements of the SCAN project are not necessarily the same as those of conventional geothermal projects: in SCAN, a single data acquisition well is drilled in a given area of interest. No geothermal energy is produced, outsteps are kept as low as possible and when data acquisition is complete the well is decommissioned. In conventional geothermal projects, however, at least two wells are required, heat is produced for long periods and distance between wells at reservoir level are generally over a kilometre.

7. List of Abbreviations

2D	Two Dimensional
3D	Three Dimensional
AGC	Automatic Gain Control
CDP	Common Depth Point
D20 wavelet	Daubechies wavelet with 20 coefficients
DUG	DownUnder GeoSolutions
EBN	Energie Beheer Nederland
Eta	Anellipticity of the P-wave phase slowness
FKK	Frequency-Wavenumber-Wavenumber
Km	Kilometre
m	Metre
ms	Millisecond
MASTT	Residual Reflection Static Calculation Software
NMO	Normal Moveout
PostSTM	Post-stack Time Migration
PreSTM	Pre-stack Time Migration
RMO	Residual Moveout
RMS	Root Mean Square
SCAN	Seismische Campagne Aardwarmte Nederland
SEG	Society of Exploration Geophysicists
SEG-Y	SEG Y Data Exchange Format (file format for seismic data)
SOF	Structurally Oriented Filter
s	Second
sps	Shell Processing Support (file format for exchange of geophysical positioning data)
TA	True Amplitude
TFDN	Time-Frequency Denoise
TWT	Two Way Time
VTI	Vertical Transverse Isotropy
WTF	Wavelet Transform Filter
XSpread	Cross-spread