G1437: Documentation on Seismic Interpretation HAL

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Prepared by:

Reviewed by:

PANterra GEOCONSULTANTS

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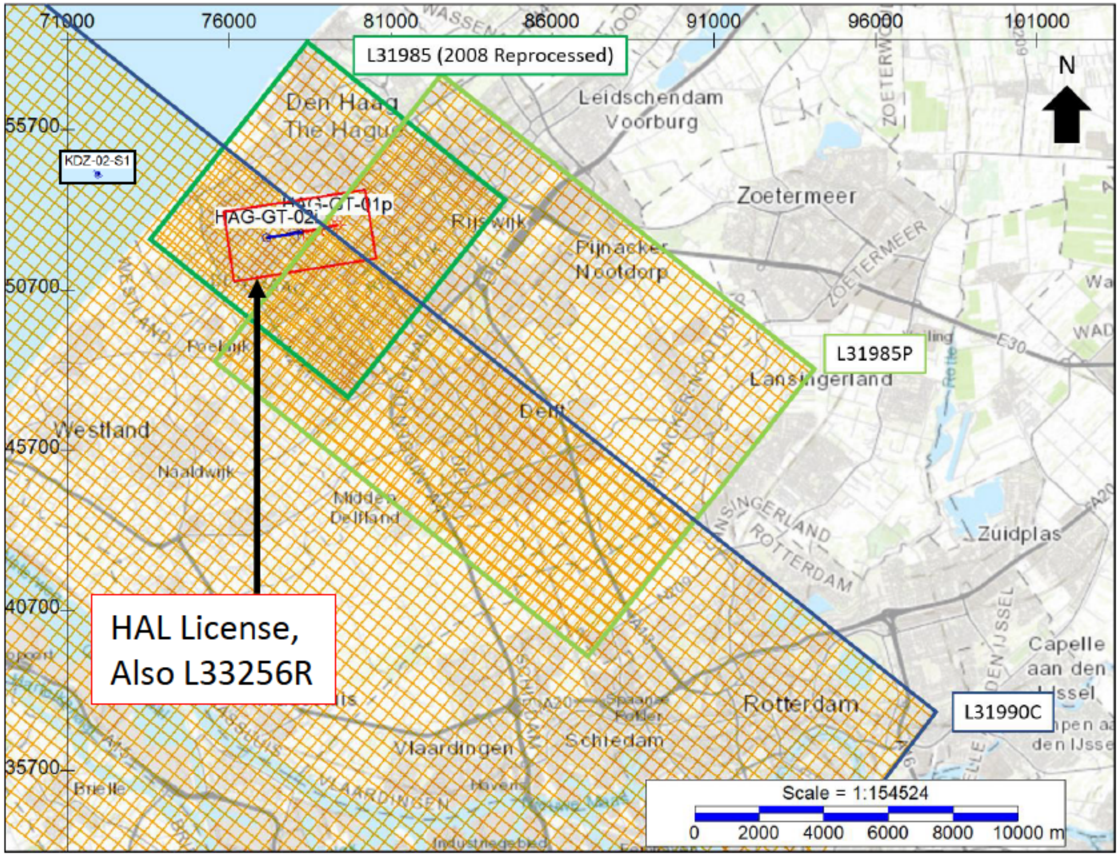
1) Review Horizon Interpretation & New Picking
2) Review Faults & Picking
3) Structural Interpretation
4) Time-Depth conversion
5) Well-test Review

1) Horizons: Available data

- L1985P
- L31985 (repro)
- L31990C
  - Used for ties to KDZ-02-S1
- L33256R
  - Only covers exact license area boundaries
  - Extremely heavy Van-Gogh filter
  - Hardly used for above reasons



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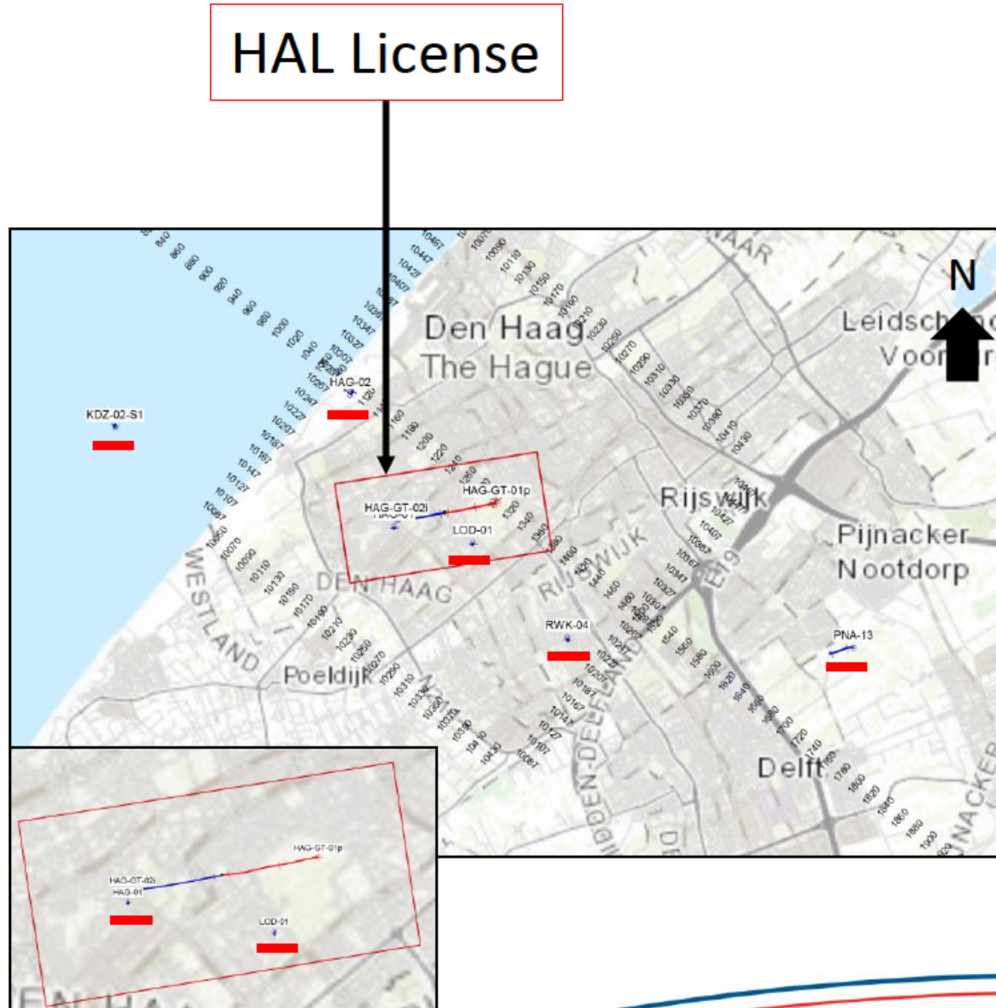
Available offset wells

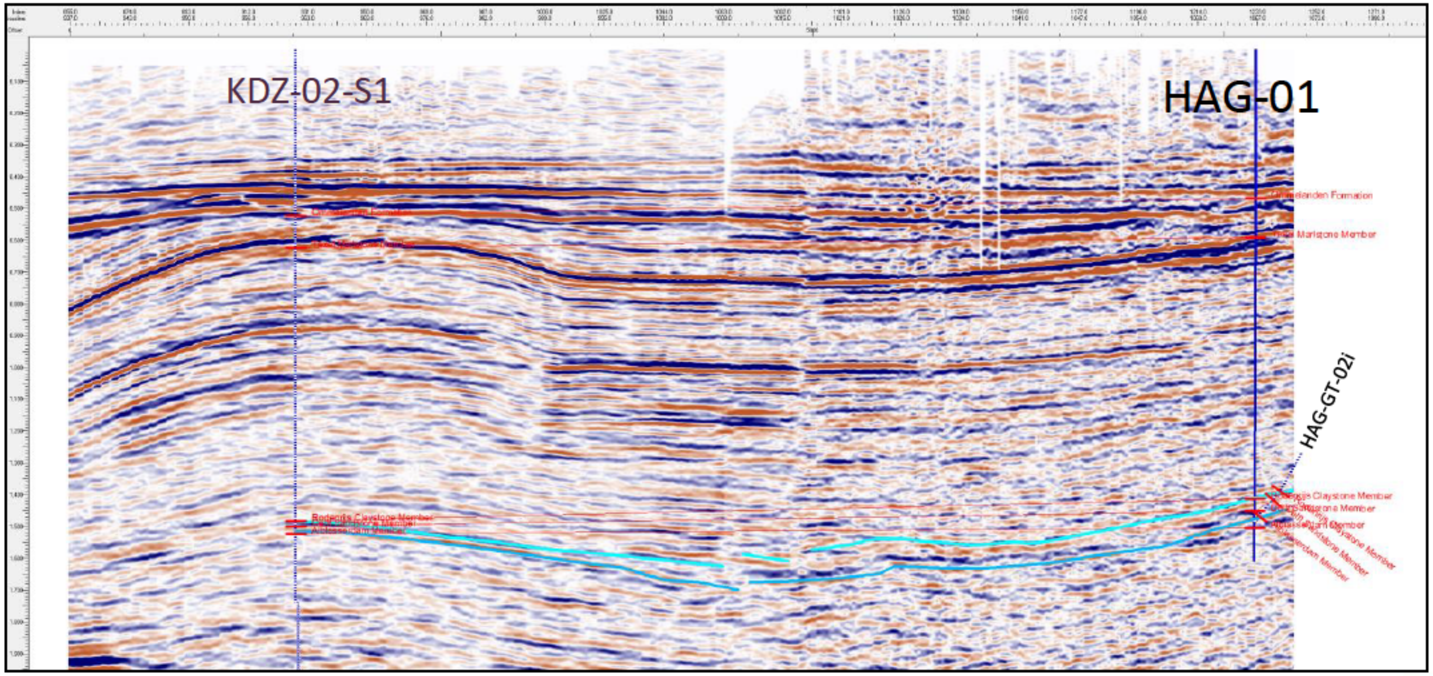
- Velocity data available:
  - KDZ-02-S1
    - Tie to Rodenrijs & Base Delft
  - PNA-13
    - Only CS, no tie possible

- Wells drilled into Delft fm. in proximity
  - HAG-GT-01
  - HAG-GT-02
  - HAG-02
  - RWK-04

- Not into Delft fm.
  - LOD-01



Tie from KDZ-02-S1 to HAL



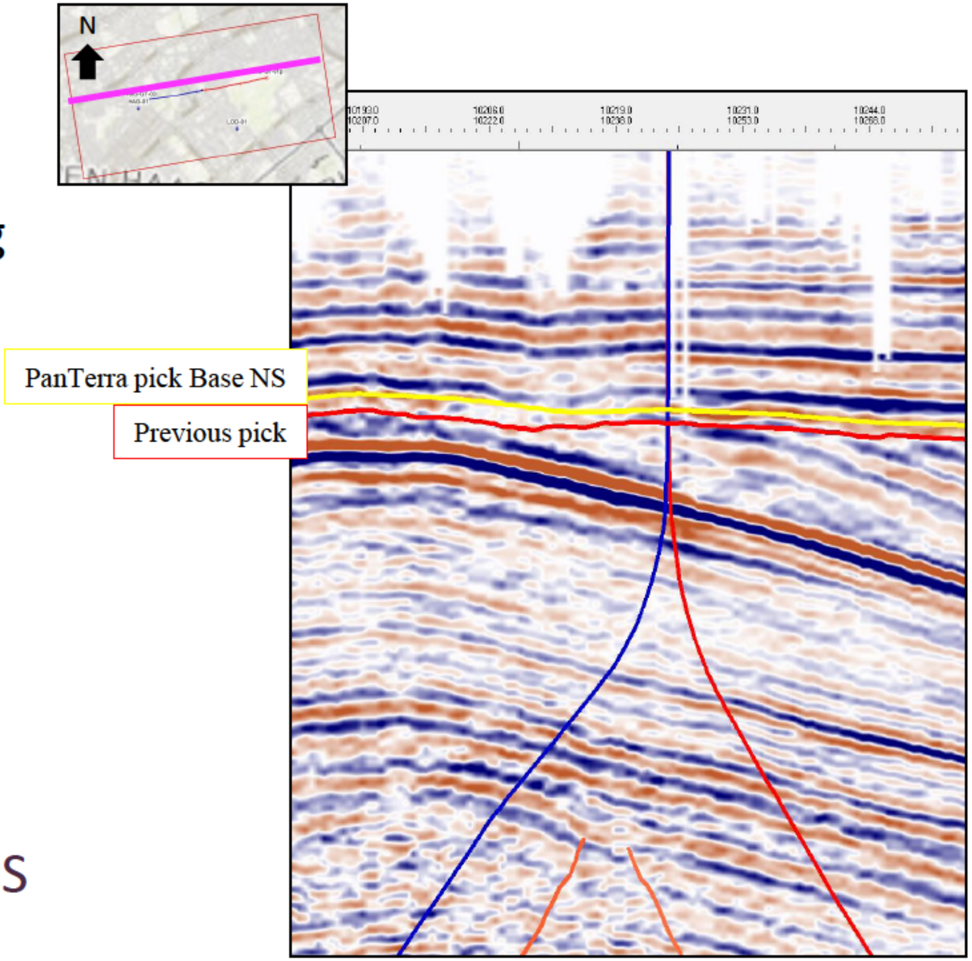
1) Horizons: Base North Sea Group

Previously

- Wide interpretation spacing (40 lines) resulted in poor grid
- General pick on soft-kick **(blue)**

PanTerra

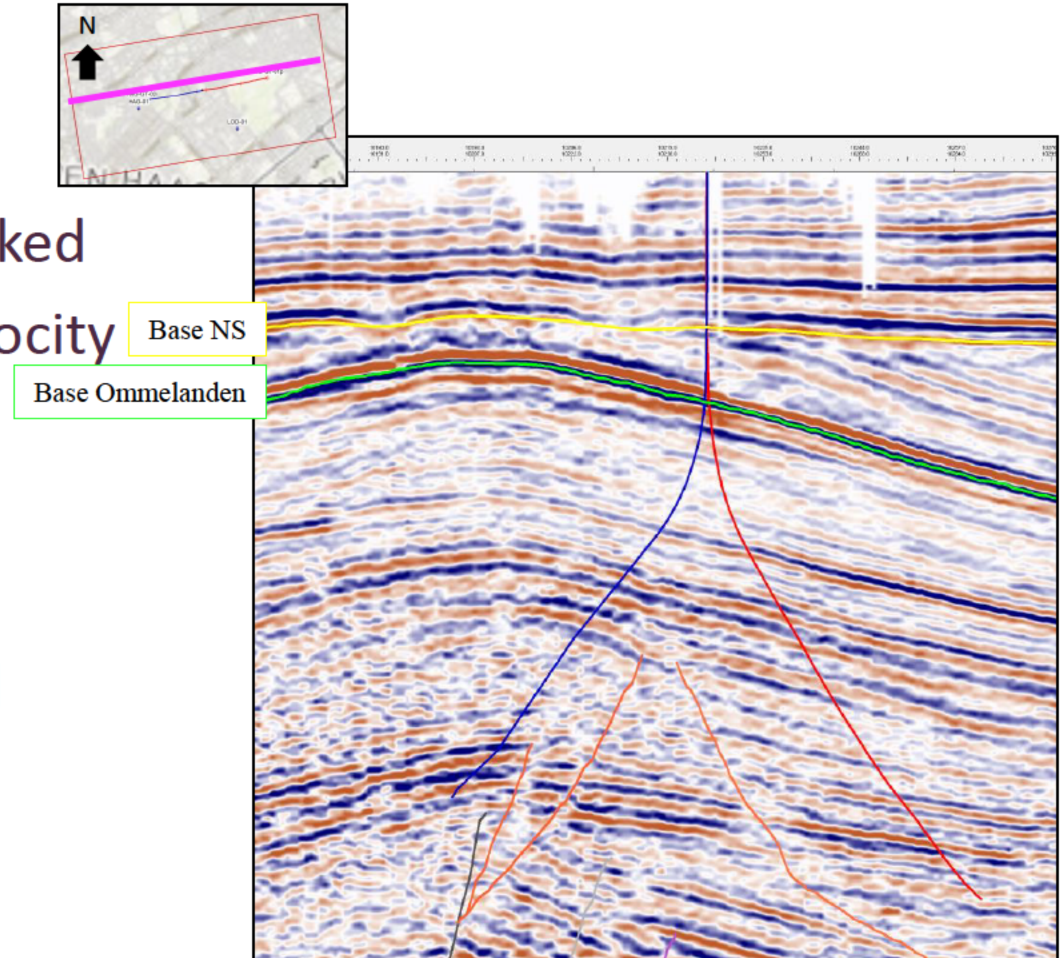
- Less-wide spacing (10 lines)
- Placed on hard-kick (red) as velocity **increases** at base NS



1) Horizons: Base Ommelanden

Previously

- Clear marker, well picked
- Soft-kick **(blue)** as velocity **decreases**



PanTerra

- No repicking required

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1) Horizons: Holland

Previously

- No marker picked between Base Ommelanden and base Vlieland
- This left a large (up to 1s TWT) gap for T-D modelling

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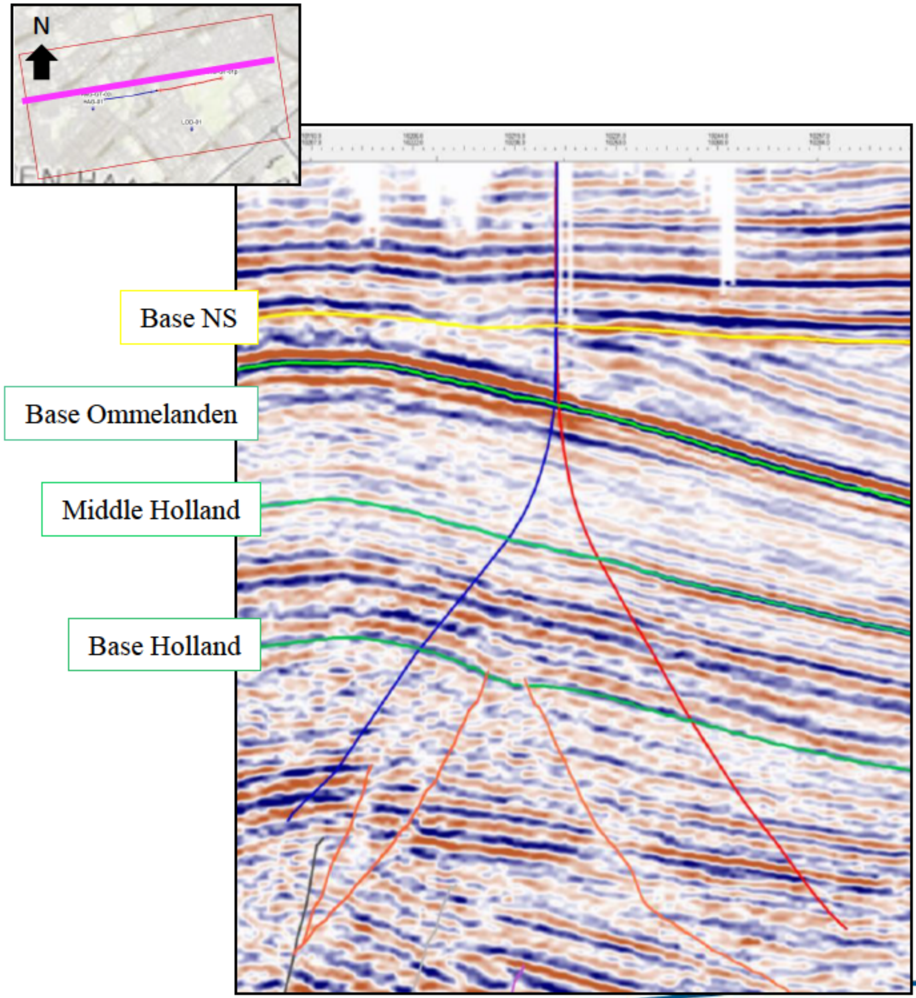
- Middle Holland & Base Holland picked
- Autotracked
- Clear markers



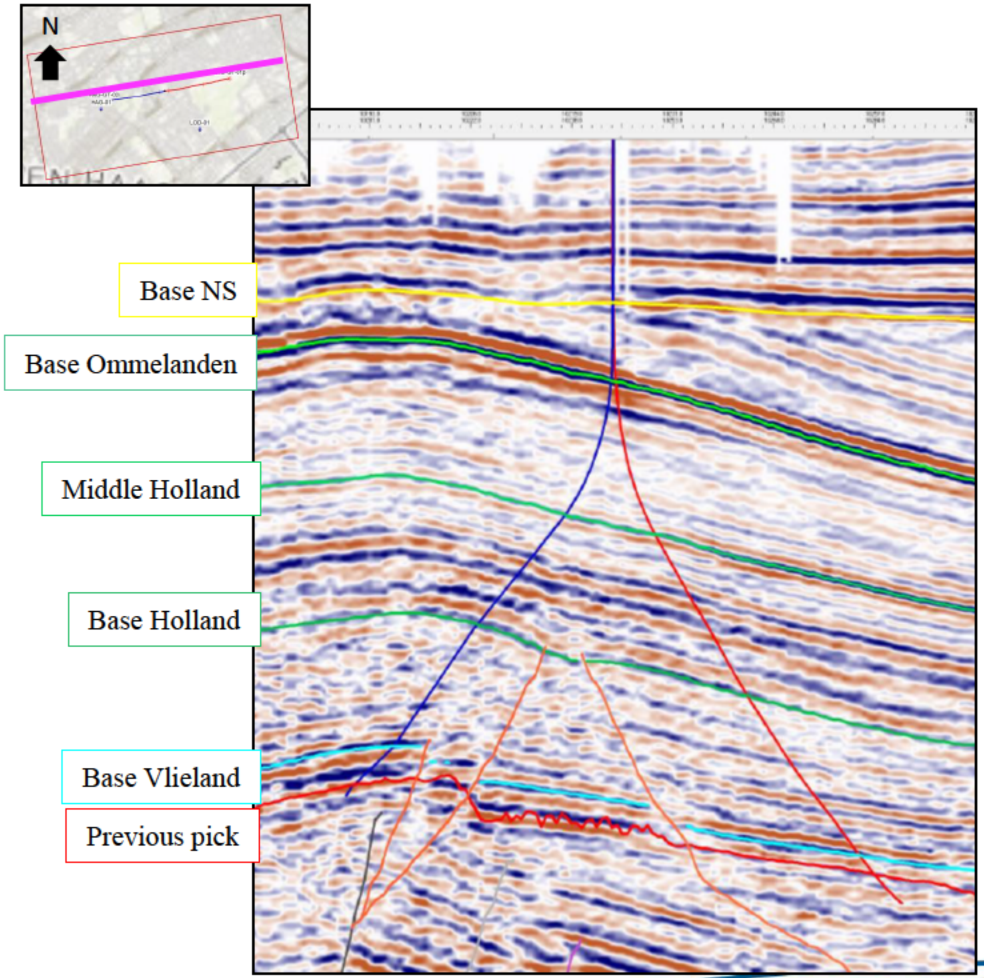
1) Horizons: Base Vlieland/Top Rodenrijs

Previously

- Picked too deep
- Inconsistent on hardkick/softkick
- Irregular grid due to high spacing

PanTerra

- Picked on softkick **(blue)** as velocity **decreases**
- Very consistent marker



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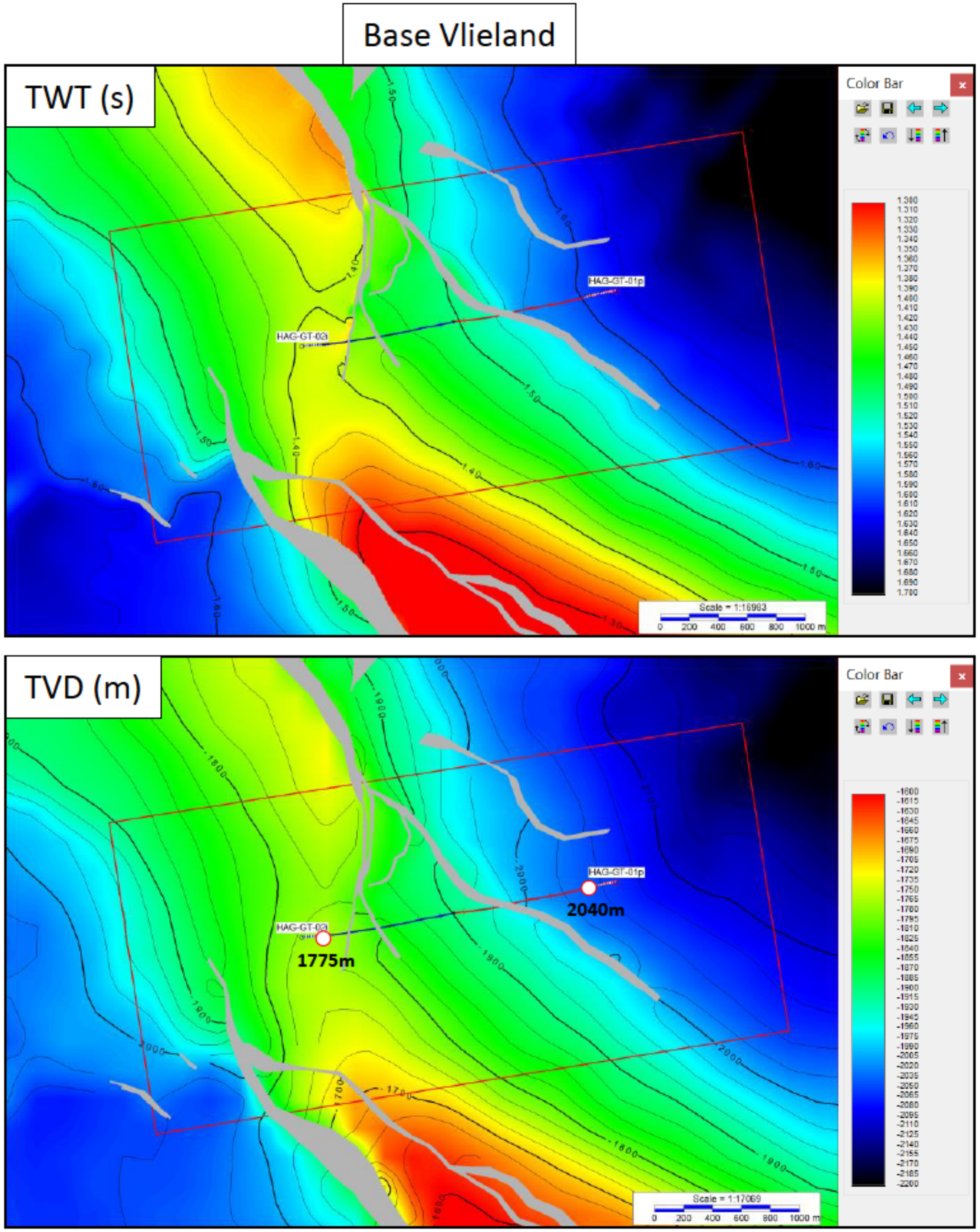
Base Vlieland map (BKN)



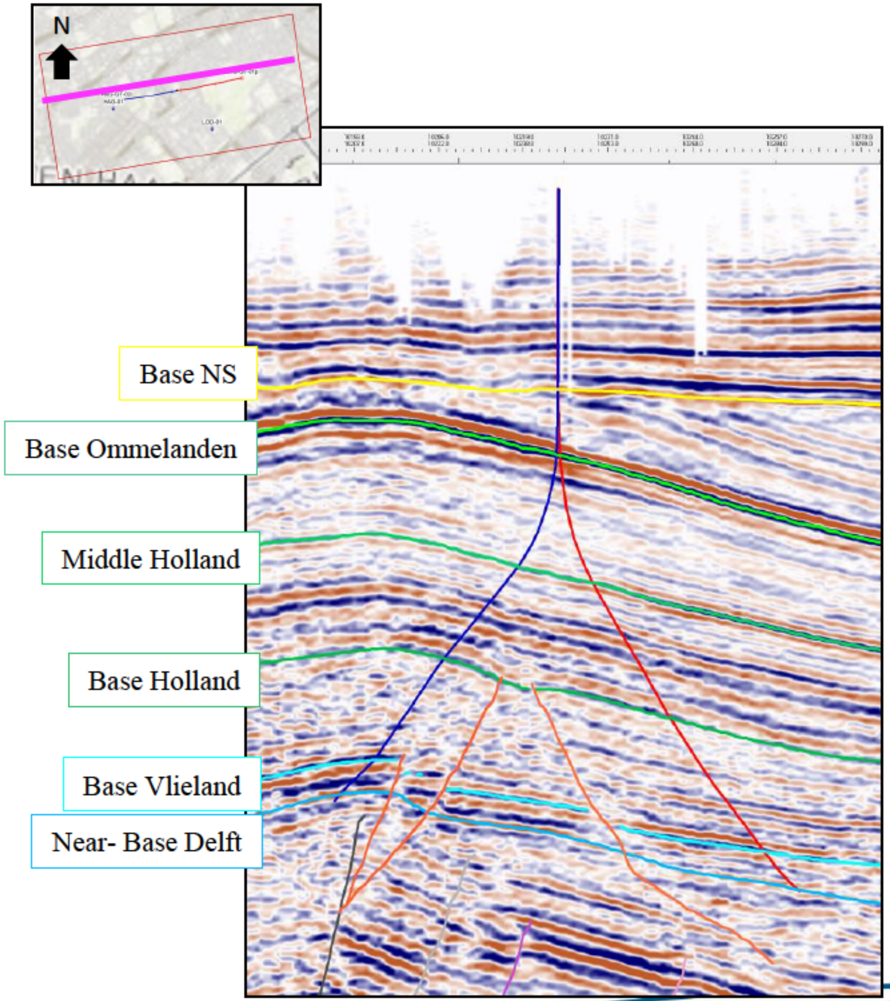
1) Horizons: Near-Base Delft

Previously

- Previously unpicked

PanTerra

- Delft is believed to lie unconformably on Alblasserdam. This is visible in multiple places in the West-Netherlands Basin
- When possible, picked on consistent hardkick (red) above unconformity as velocity **increases** at the Base Delft.
- Manually picked, dense picking



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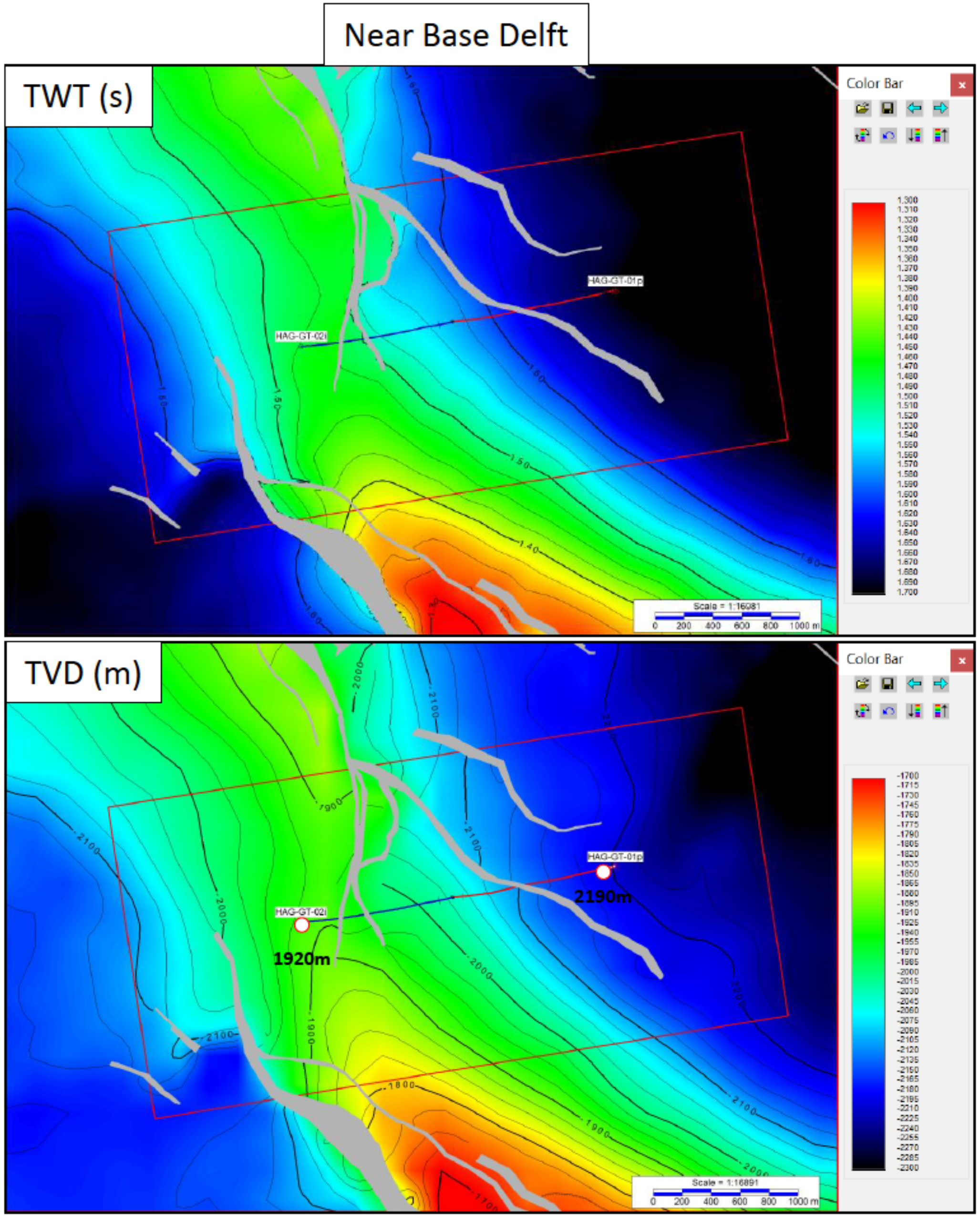
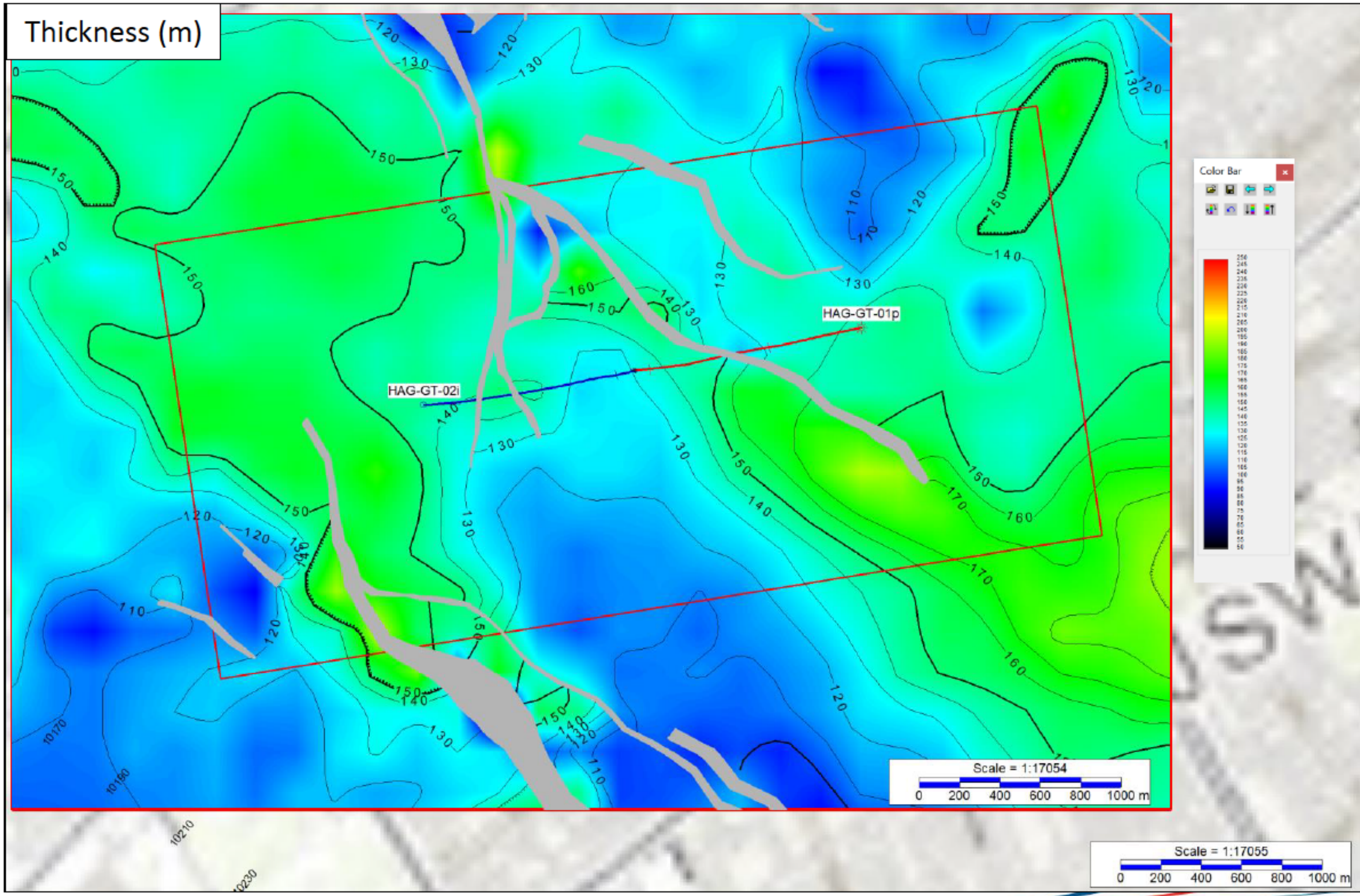


Near Base Delft map

Thickness Base Vlieland to Near-Base Delft



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1) Horizons: Base Alblasserdam

Previously

- Picked too deep in grabens
- Irregular grid due to spacing

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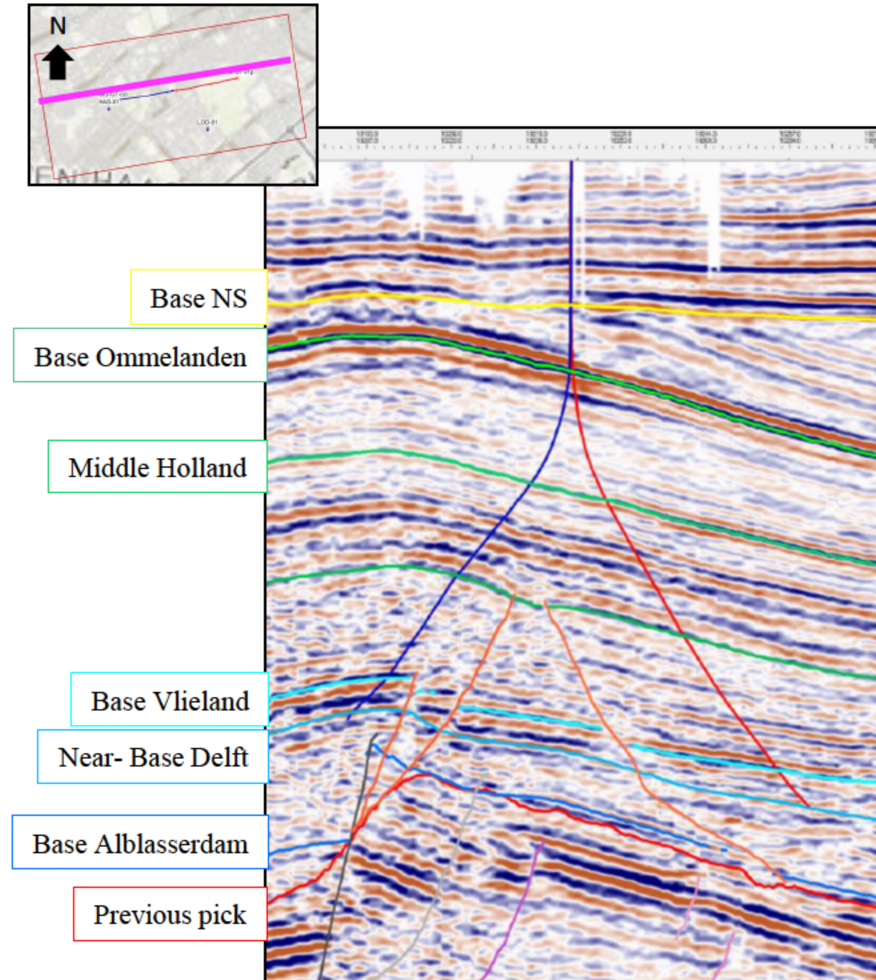
- Picked as hardkick (red) with onlap throughout Alblasserdam.
- Base of onlap is the base of the Alblasserdam



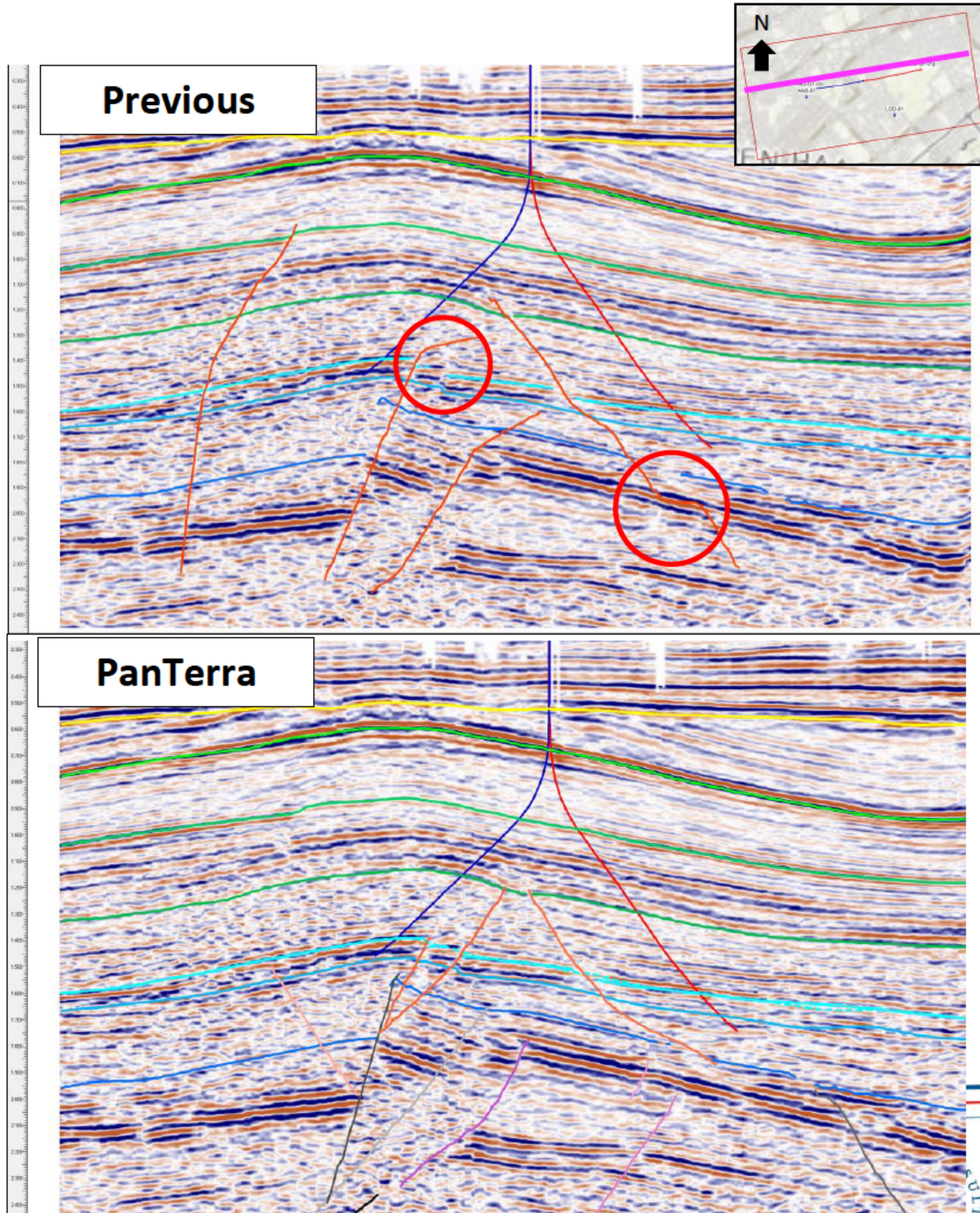
2) Faults

Previous

- Not enough detail to show HAL structure
- Unlogical connections
- Erratic fault surfaces

PanTerra:

- Picked in more detail around reservoir
- More consistent picking with interpretation of area in regional structural context



2) Faults

Faults are divided into **two** groups

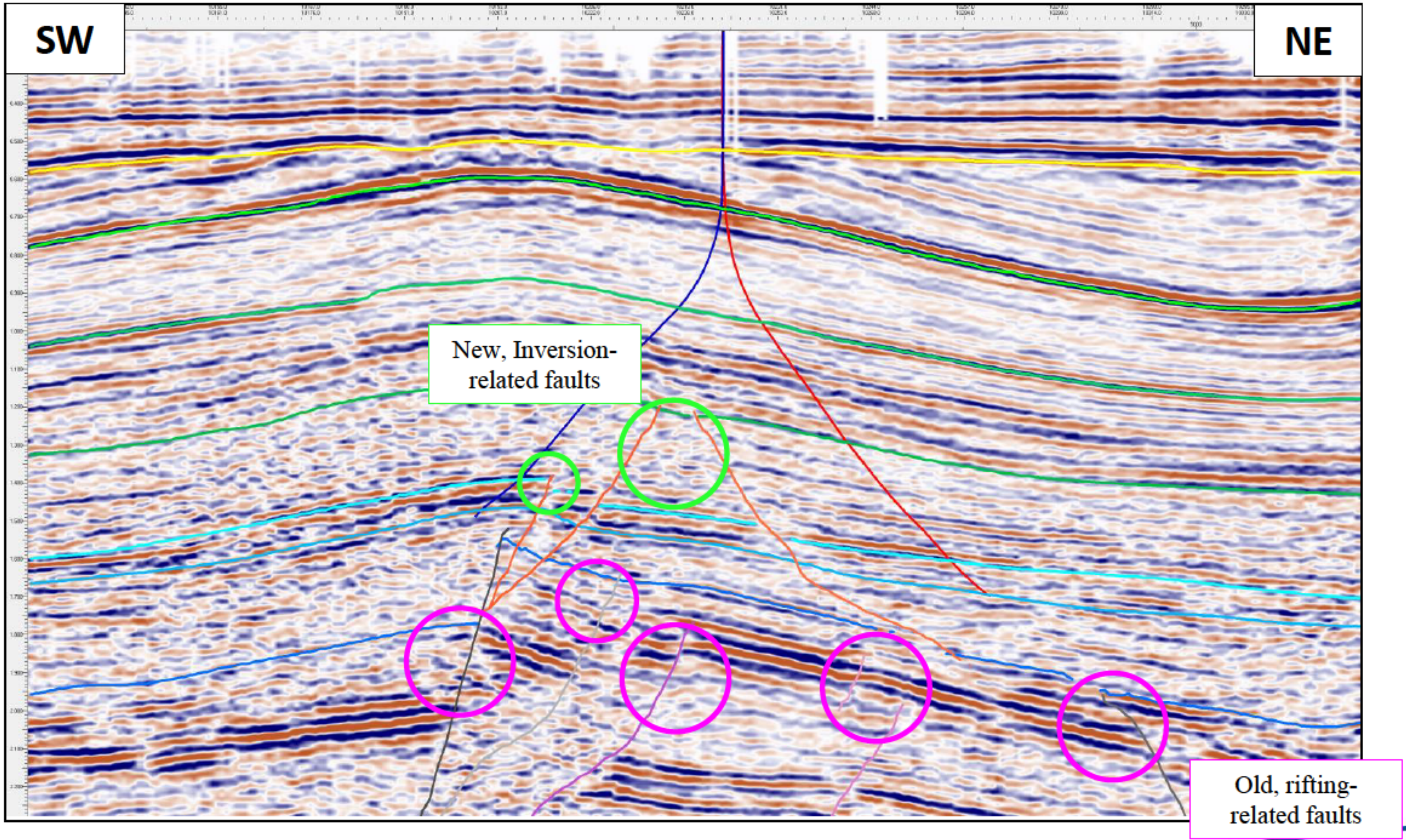
1. Pre-Delft rifting-related faults

2. Post-Delft Inversion-related faults

- These are **not** interpreted to be the same faults. They will most likely be linked but not in the form that an old normal fault is reactivated as an extended reverse fault connecting basement to base NS

2) Faults

N
HAG-GT-01
HAG-GT-02
DEN HAAG
RIJSWIJK



SW
NE
New, Inversion-related faults
Old, rifting-related faults

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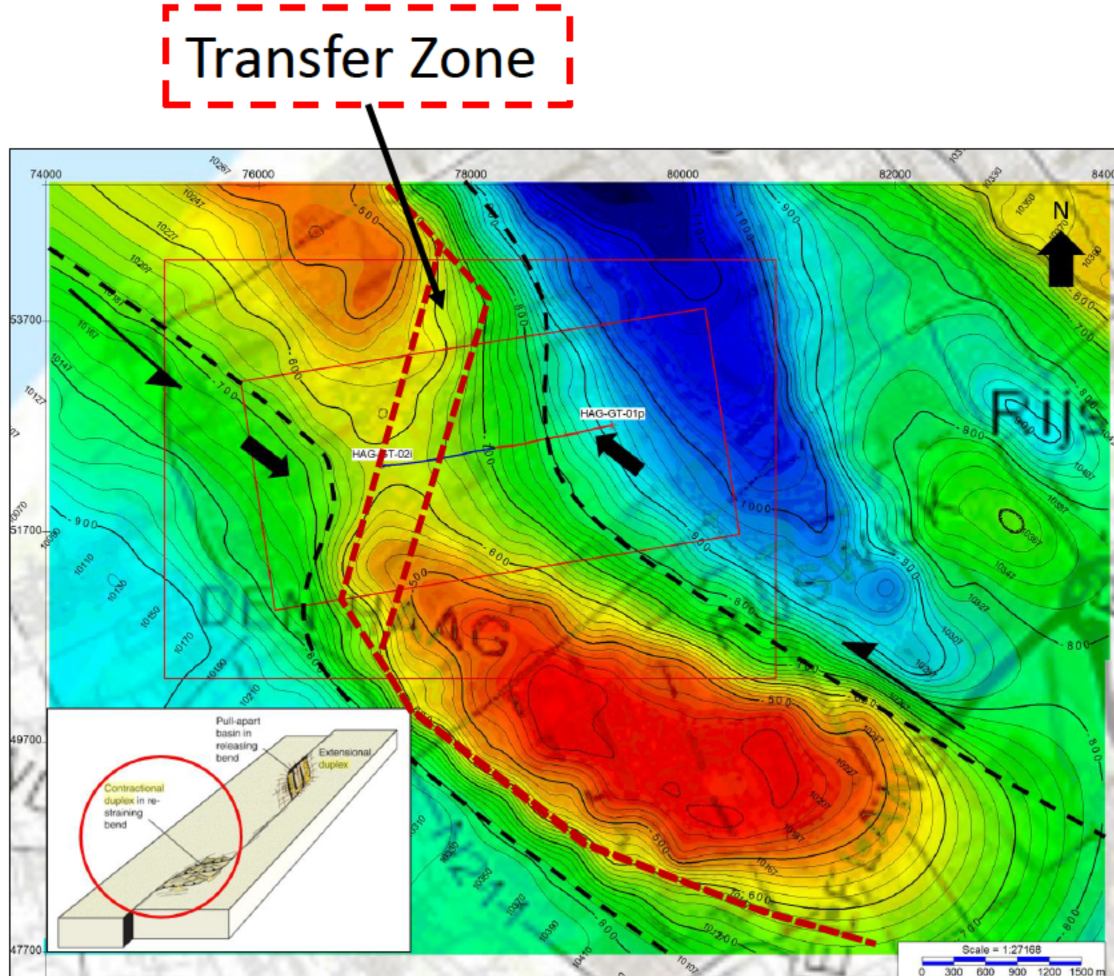
3) Structural Interpretation

The injector HAG-GT-02i is drilled in a major fault zone, in a compressional bend.

The well is positioned in the transfer zone. This result in a denser fault network around this well.



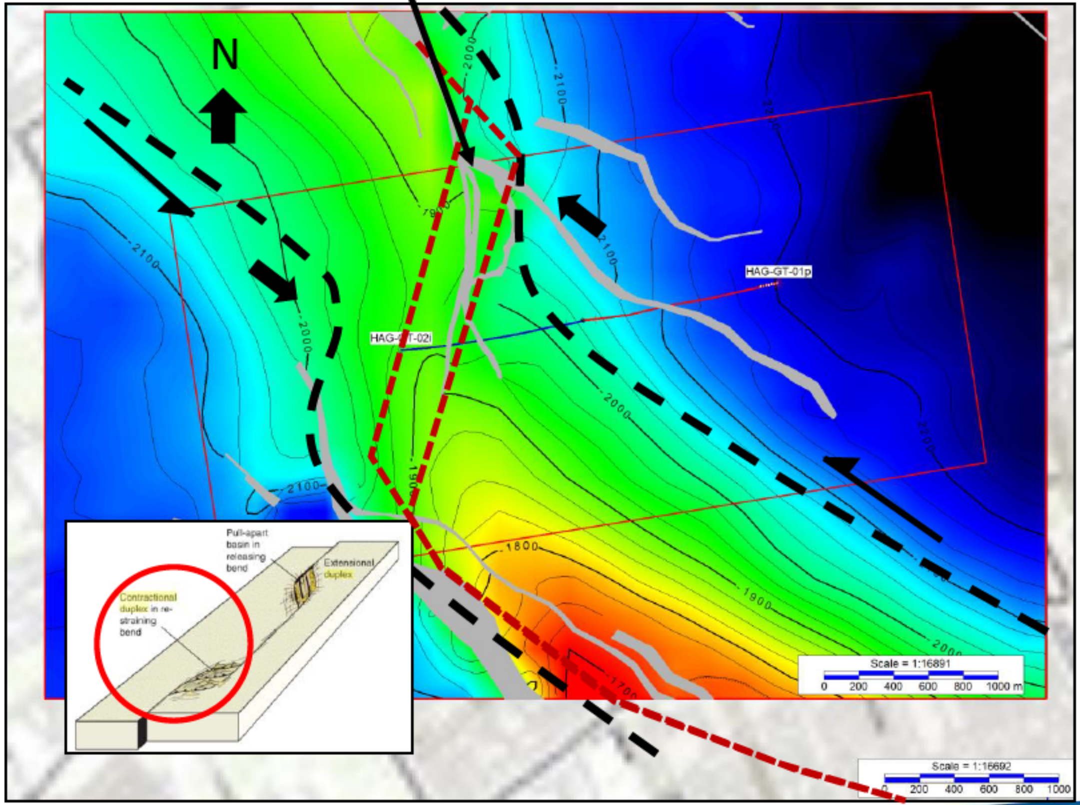
Base Ommelanden depth map

3) Structural Interpretation

The injector HAG-GT-02i is drilled in a major fault zone, in a compressional bend.

The well is positioned in the transfer zone. This result in a denser fault network around this well.

Transfer Zone



Near-Base Delft depth map

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4) T-D Conversion

- v0*k model derived from velmod and applied before had high error (up to 7%)

- Preliminary v0*k model matches well
  - Includes local wells, also GT wells in grabens
  - <1% error
  - Applicable on request

- PanTerra prepared a simple local average velocity model to construct depth maps for the SRA, based on horizon time in the geothermal wells and the depth in the well.
  - Average velocity model based on time-depth pairs in HAG-GT wells
    - Error **Base Vlieland** HAG-GT-01: 3.3%
    - Error **Base Vlieland** HAG-GT-02: 3.6%

PanTerra average velocity model

HAG-GT-01p					HAG-GT-02i				
Fm	**TWT**	**z(mTVDRT)**	**Vint**		**TWT**	**z(mTVDRT)**	**Vint**		**Avg**
Base North Sea	0.524	497	1896.947		0.524	496	1893.13		1895.038
Base Ommelanden	0.679	716	2825.806		0.677	715	2862.745		2844.276
Base Holland	*1.279*	*1567*	*2836.67*		*1.158*	*1427*	*2960.5*		2898.583
Base Vlieland	1.601	2109	3366.46		1.39	1711	2448.276		2907.368
Base Delft	1.692	2286	3890.11		1.472	1864	3731.707		3810.909

5) Well test review

Well Test Date	Reference report	Well	Model type	Total Skin	Permeability, mD	Net thickness m TVD	Dist. To Fault [m]	Overall Quality of Test
June 2012	27.233/56193/BP IF Technology	GT-01	infinite	30±15	710	65	n.a.	Poor
June 2012	27.233/56193/BP IF Technology	GT-02	infinite	140±40	860	97	n.a.	Poor
June 2012	TNO 2012 R10268	GT-01	infinite	42	107	62	n.a.	Poor
June 2012	TNO 2012 R10268	GT-01	infinite	126	271	97	n.a.	Poor
Feb. 2018	Analysis of Welltest HAG-GT-02, Pieter Lignen et al.	GT-02	Finite model, spherical flow	7 (partial penetration)	1400	96	770	good
Feb. 2018	Analysis of Interference between HAG-GT-01 & HAG-GT-02	Interference	Finite model	n.a.	280	81	Several faults, channel width is over 3 km	good
March 2018	Analysis of Welltest HAG-GT-01, Pieter Lignen et al.	GT-01	Finite model	20 (partial penetration)	2300	62.5	1400	good

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5) Well Test Review

2012 Well test

The relatively poor-quality pressure data from the well test in June 2012 used by IF Technology and TNO, resulted in overall poor-quality interpretation. Beside the poor quality of the data set, simple and inappropriate analysis approaches were used for the interpretation.

The IF Technology and TNO reports do not provide a log-log plot of the pressure and derivative. The quality of the match could not therefore be determined.

The reservoir model used for the test interpretation is infinite radial. IF Technology stated that no late-time boundary effects could be seen from the test. The well-test evaluations would suggest both of the wells to have large positive wellbore damage (skin up to 140). This is considered very unrealistic and likely the result of a wrong selection of the middle-time period (transient-time period), which allows the determination of reservoir permeability and total wellbore skin. Alternative interpretations were not tested, such as partial penetration (spherical flow) and more complex reservoir characteristics. The results from 2012 well test, therefore, are considered to be unreliable.

5) Well Test Review

2018 Well test

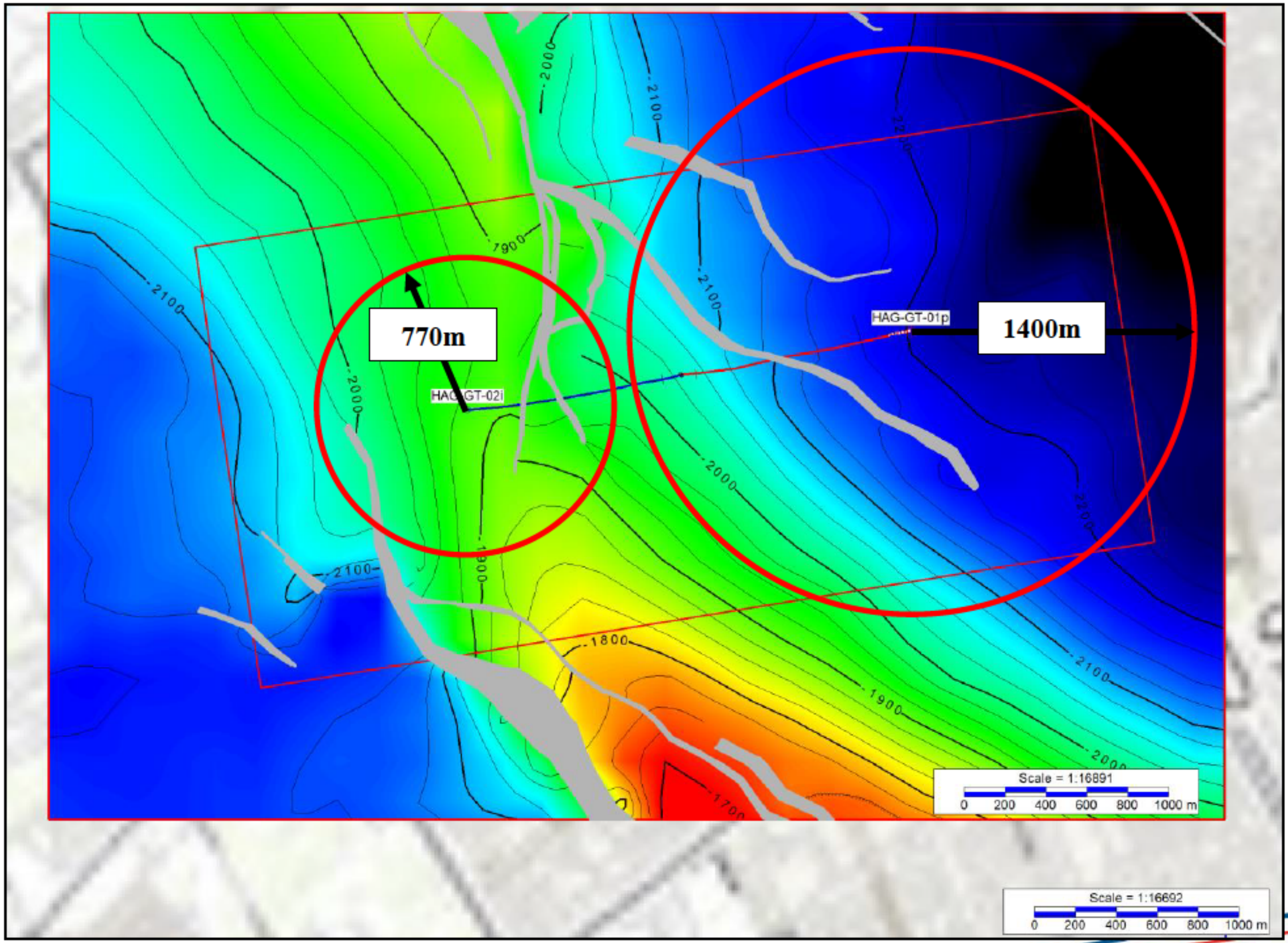
In February and March 2018, the wells HAG-GT-01 and GT-02 have been stimulated to remove the formation damage. After stimulation both wells have been tested and the pressure data were interpreted by Pieter Lingen et al (2018). In general, the data quality of the test was high and made it possible to derive clear conclusions. A clear and appropriate interpretation was also performed.

Well HAG-GT-02 was production tested from 22 to 24/02/2018 by a multi-rate test, followed by a shut-in period of 12 hours. The production rates, generated by Nitrogen injection in a coiled tubing, varied between 19 and 106 m3/hr. Cumulative water produced was about 1680 m3. Based on this test, the static reservoir pressure is estimated to be 180.5 bara and reservoir temperature is about 73 ºC. at 1782m tvd. The estimated average reservoir permeability is about 1400 mD assuming that the whole net sand of 96 m contributes to flow. A flow barrier (possible a non-sealing fault) at 770 m was required for an optimum model match. The total skin varies from 7.15 at 105.9 m3/hr to 1.62 at 19.8 m3/hr. This indicates a damage skin of only 0.6, with most flow resistance caused by friction in the liner and screens.

During the test of HAG-GT-02, high-accuracy pressure gauges were installed in HAG-GT-01 in order to measure the pressure interference between both wells. The results of the test show a clear reaction in GT-01 on the production of GT-02, proving communication between both wells. It was difficult to get a good model match and the existence of several partial faults between the well. In spite of this partial fault, the communication between both wells is certainly good enough for water circulation with an effective average permeability of 280 mD. A closed rectangular model with a channel width of over 3 km was used. The exact size of the connected area could not be established but estimated larger than 38 km2.

Well HAG-GT-01 was production tested from 18 to 20/03/2018 by a multi-rate test, followed by a shut-in period of 12 hours. The production rates, generated by nitrogen injection in a coiled tubing, varied between 15 and 130 m3/hr. Cumulative water produced was about 1870 m3. The transient productivity index (PI) after 113 hours flow is 21 m3/hr/bar. The estimated average reservoir permeability is about 2300 mD assuming that the whole net sand of 62.5 m contributes to flow. A flow barrier at about 1400 m is possible. Skin is high at 20, caused by the partial penetration as only 36 % of the total k*h is open to the flow.

Near-Base Delft vs Well tests



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