Internship report

Hydrocarbon Shows database: the power of systematic analysis

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February, 2017

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Abstract

Hydrocarbon (HC) shows can be concisely defined as significant increases of HC gases or fluids coinciding with changes in lithological properties. HC shows may provide valuable information with respect to HC migration paths, kitchen maturity and source rock typing in the Dutch subsurface. Therefore, the HC shows are documented in a well-structured database.

The goal of this project is to expand the HC shows database towards the south and make improvements when required. In this study the HC show classification have been refined to self-explanatory classifications that are uniform for all three data types used in the database. Additionally, a more detailed classification system to describe HC observations in well tests has been designed. An extensive QC has been performed by actively searching for inconsistencies and errors in the HC shows database. This QC resulted in a list of common user input errors that are now checked for automatically. Spotfire has been used in this project for several studies including a regional HC source rock study; a comparison between a missed pay analysis by Panterra and the HC shows database; a study investigating the effect of mud type on gas readings; and a study on the effect of lithology on HC show classifications. Spotfire is proven to be a powerful tool for analyzing the HC shows database. Furthermore, a positive correlation was found between test data and mudlog data indicating a high database quality. Lastly, the project has been handed over successfully to my successor. To his aid the workflow for the HC shows database has been reviewed and updated with the latest improvements. Additionally, two chapters were added to the HC shows example ATLAS that future analysts can refer to.

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1 Introduction

Over the last decades several hundreds of exploration and production wells were drilled in the Dutch subsurface. Vast oil and gas reservoirs were discovered and the boreholes with good hydrocarbon (HC) potential were exploited. By now most of the smaller fields in the Dutch offshore are mature fields with a decreasing production capacity. Discovering new HC reservoirs becomes increasingly more expensive and challenging. Therefore, it is important to use all available data in future exploration studies. All data recorded when drilling a borehole, being either successful or unsuccessful, is collected by TNO in a database which can be accessed through the nlog website.

The nlog website has been used as basis for several databases and studies and also contains information on HC shows. HC shows are defined as “any indication of hydrocarbons, i.e. stain, fluorescence, cut fluorescence or any increase in drilling mud gas of reasonable percentage above background” (Crain, 2015). A good HC show can be a reason for further testing or formation sampling (Crain, 2015). Also, HC shows may provide information on source rock typing, kitchen maturity and migration paths. For these reasons the EBN HC shows database has been designed in which information on HC shows is interpreted and collected for as many boreholes as possible in the Dutch subsurface. Analyzing all available HC show data in one comprehensive database makes a powerful exploration tool.

At the start of this project 448 boreholes had been analyzed. These were all situated in the northern A to H, M and N offshore quadrants (see Figure 1.1). Also, a start had been with analyzing the L quadrant. Former UU student Chris Heerema designed the initial database and evaluated the results through a pilot study. Youri Kickken (UU) and Claudia Haindl contributed to the expansion and development of the database. Also, Youri Kickken revised the HC show workflow and designed extensions and manuals to visualize the database in Petrel and QGIS. In this project more boreholes in the L quadrant will be analyzed and the HC show database usability will be extended and demonstrated.

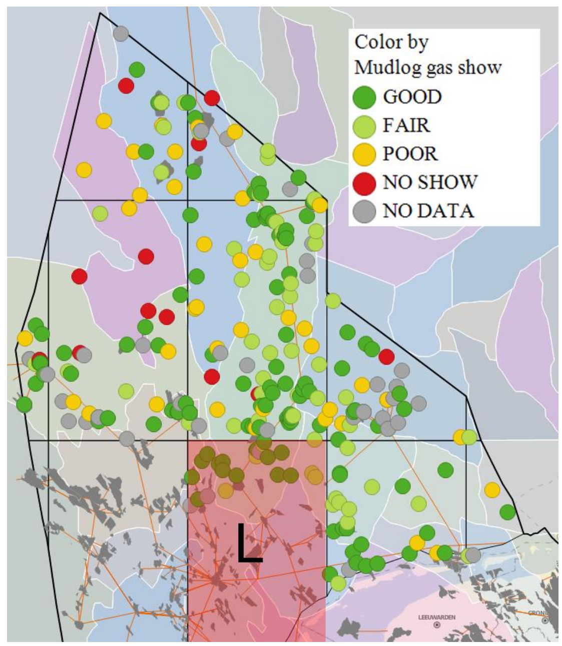

Figure 1.1: Locations of wells that have already been analyzed. The target area of this project is colored red.

1.1 Long-term goal of the HC show database

The primary goal of the HC show database is to make HC show data easily accessible. The final EBN HC show database will comprise all on and offshore boreholes in the Netherlands. Each borehole will be analyzed using its mudlog data, test data and (sw-)core data. These three data types make for a strong tool to identify and qualify HC occurrences. Because EBN acts in the interest of the Dutch petroleum industry as a whole, it is EBN’s long term aspiration to make the HC show database available to its partners.

1.2 Goals of this project

This internship project can roughly be divided in two parts. In the first part the database will be expanded further into the L-quadrant using the existing methodology. In the second part of the project the methodology and design of the database will be improved. The focus will be on the following subjects:

- Expanding the HC show database into the L quadrant.
- Making the database more user friendly by designing self-explanatory HC show classifications according to the MECI principle and limiting the total number of HC show classifications.
- Increasing the database functionality with existing data.
    - A 'raw_gas_show' show classification based only on gas measurements is added.
    - A more detailed classification system for DSTs and RFTs is implemented and tested.
- Visualizing the HC shows database in Spotfire to generate maps that enable swift regional HC exploration studies.
- To perform regional studies with the HC show database to demonstrate the usefulness of the current version of the database. Studies described in this report are:
    - A regional source rock study.
    - The effect of mud type on gas chromatograph readings.
    - A comparison between the 'excel deviatie tool' and the HC show database.
    - Exploratory study to identify missed pay by combining the HC show database and a Panterra missed pay analysis.
- To perform a QC of the HC show database by correlating mudlog data and test data.

1.3 The HC shows database

"A HC show can be defined as a significant occurrence of hydrocarbon gases or fluids detected from the drill mud stream and identifiable as being the result of the drilling of specific formation intervals" (Yassin, 2012). "The coincidence of an increased hydrocarbon reading, with a change to potentially porous and permeable lithology, requires more detailed investigation" (Verçan, 2010).

HC shows are first observed in mudlog data and can be confirmed in well tests and cores. Therefore, three data types comprise the HC shows database:

- Data type 1: **Mudlog data**
  When drilling a borehole HC readings and lithology are logged on mudlogs, composite logs or formation evaluation logs. This data is analyzed in combination with the TNO defined stratigraphy. The best oil and gas show per stratigraphy are documented and relevant information is described.

- Data type 2: **Test data**
  Two types of well tests are documented in the HC shows database: Drill Stem Tests (DST's) and Repeat Formation Test samples (RFT samples). Only after a complex analysis it is decided whether a reservoir will be tested. Therefore, test data serves as both a confirmation and QC for the Log data.

- Data type 3: **(Sidewall-)core data**
  The goal of this category is to classify HC shows using HC descriptions from core and sidewall-core data. The main focus is to describe oil shows, however, in rare cases gas shows will be

described as well. Because coring may disrupt log data it is an important observation. Just like Test data, this category serves as both a confirmation and QC for the Log data.

2 Methods

2.1 HC shows database workflow

The latest workflow box model for the HC shows database is shown in Figure 2.1. The following changes have been made to the original Workflow designed by Kickken, 2016. 'NLOG stratigraphy' moved from GISbase updates (step 3) to data analysis (step 1) (the stratigraphy is not updated in the GISbase). Columns with the 'Strat_group_code', 'TVD', and 'deviation data' were added to the GISbase (step 3) (before only the wellhead coordinates were added). 'Spotfire project' added to 'output' and 'visual'. Using this box model of the workflow new analysts can easily make improvements to the HC shows database project by evaluating all steps individually.

The TNO defined stratigraphy and mudlog, test and (sw-)core data data will be gathered from the nlog website. If the required data is confidential it can often be obtained from Livelink (EBN's file storing database). For a more detailed description of the 'Input' and 'Data analysis' (step 1) refer to the Workflow in Appendix A. The HC shows datasheet will be uploaded regularly (preferably once a month) to the GISbase (step 2). The GISbase is EBN's database (MS SQLserver) in which geodata is stored and updated. All borehole related data that is relevant to the HC shows database can be updated from the GISbase (e.g.

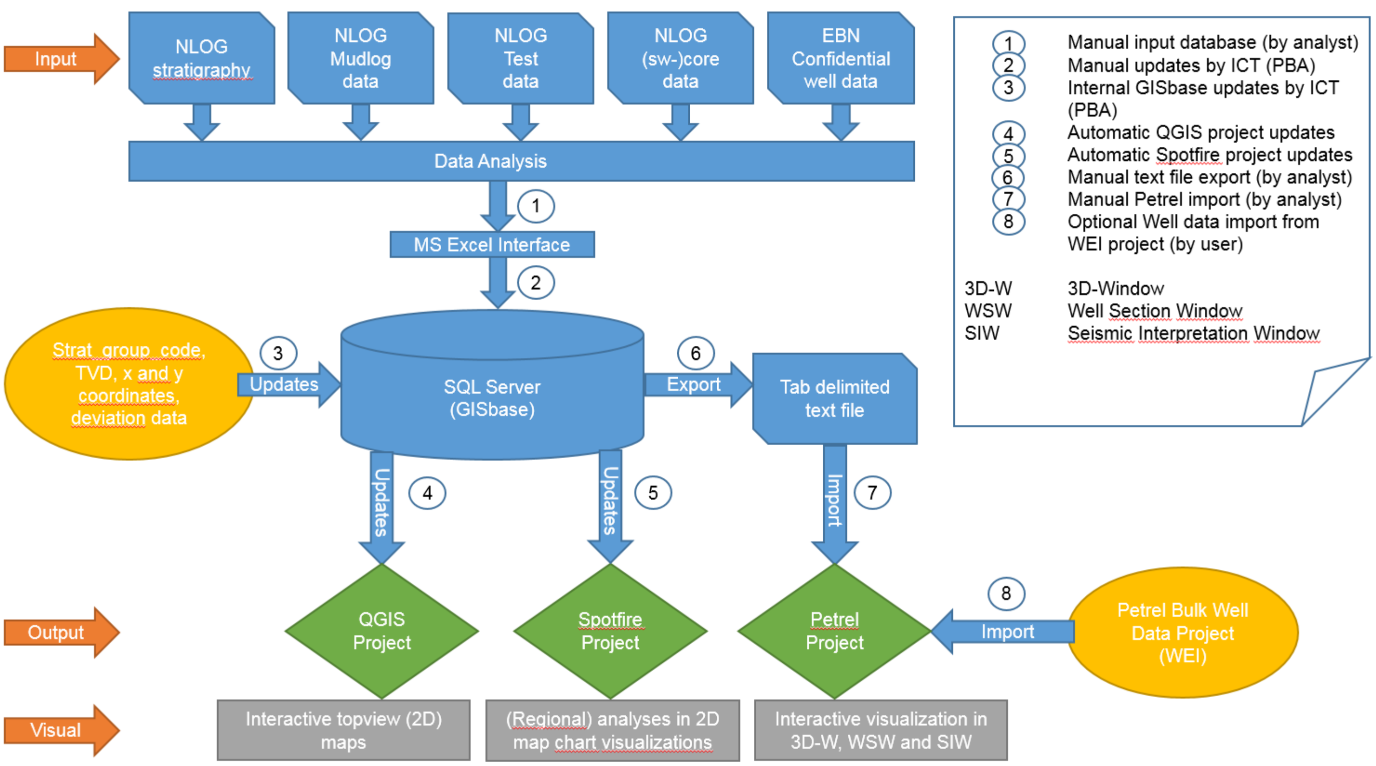

Figure 2.1: The latest HC shows database workflow represented as a box model.

borehole coordinates and deviation data). Finally, the output of the GISbase can be analyzed in three programs. QGIS allows for an interactive 2D top view visualization (step 4). Regional quantitative analyses combined with an interactive 2D top view visualization can be performed in Spotfire (step 5). In Petrel several complex analyses combined with an interactive 3D visualization are possible (step 6-8).

2.2 Columns changed in the HC shows database

The adaptations that have been made to the HC shows database are summarized below. Columns have been added, removed and renamed in the 'Log data' and 'Test data' spreadsheets. No changes have been made to the '(SW-)core Data' spreadsheet. More detailed explanations of several adaptations are given in other sections.

Log data

- The 'STRAT_NAME' column has been removed. This column showed the full stratigraphic name belonging to the stratigraphic codes in the column to its left. This column has been removed because it was incompletely filled and most users will know the stratigraphic names by heart.
- A 'raw_gas_show' column was added. The 'raw_gas_show' classification depends only on the peak and background gas readings. All aspects of the lithology are ignored. The 'raw_gas_show' is explained in more detail in section 3.1 and its Excel formula can be found in Appendix B.1.
- The 'gas_show' column has been renamed to 'interpreted_gas_show' to emphasize its difference from the 'raw_gas_show' column and clarify its dependence on the analyst's interpretations.
- A column with the along hole depth of gas shows was added. The 'AH_depth_gas' allows HC shows to be visualized along the trajectory of the borehole, i.e. the depth of a gas show can be used to calculate its true position in x, y and z coordinates. The 'AH_depth_gas' Excel formula can be found in Appendix B.2.
- An 'user_input_check' column was added. This Excel formula returns an error indicator if a common user input error is recognized. E.g. if the 'background_gas' is larger than the 'total_HC_gas' or if a shows is described but no lithology is entered. The 'user_input_check' is described in more detail in section 3.6 and its formula can be found in Appendix B.3.

Test data

- The 'Result' column has been renamed to 'HC_result' to emphasize that this column contains the classifications of both gas and oil shows.
- A 'gas_show_result' column containing only test gas results was added to the database. The 'gas_show_result' column gives users quick access to the test data in which gas shows were identified. From the 'HC_result' column only it is not possible to separate oil shows from gas shows because they use the same classifications.
- An 'oil_show_result' column containing only test oil results, was added to the database. The 'oil_show_result' column gives users quick access to the test data in which oil shows were identified.
- A 'max_flowrate_(m3/d)' column was implemented. In this column all the DST flow rates are converted to m^3/d which makes it easier to compare DST results. To convert from cubic feet to cubic meters the following conversion factor is used: 1 feet is 0.3048 m. To convert from barrels to cubic meters the following conversion factor is used: 1 cubic meter is 6.2898 barrels.
- A 'data_quality' column was added for two reasons. Firstly, to be consistent with the 'Log data' and '(SW-)core Data'. Secondly, a quality label is required to determine the reliability of analyses.

2.3 Refining HC show classifications

When expanding the HC shows database several indistinct HC show classifications were recognized. Also, the employment of HC show classifications was found to be inconsistent for the three different data types. For these reasons the HC show classifications have been refined. The new HC show classifications were designed to meet the following requirements:

- The classifications should be self-explanatory.
- The classifications should describe all possible HC shows. For this the MECE (mutually exclusive and collectively exhaustive) principle was applied.
- The total number of classifications should be limited.
- Uniform classifications should be used to describe HC observations in the 'Log data', 'Test data' and '(SW-)core Data' spreadsheets.

Refining 'Log data' HC show classifications

Table 2.1 shows the previous and updated HC show classifications used to describe mudlog data. If
2.3.1 adequate data is available to rate a gas or oil show the classification does not change and it is given either a GOOD, FAIR, POOR, OIL SHOW or NO SHOW rating. For the cases in which no data is entered in the HC shows database (because the borehole has a sidetrack and should not be duplicated) or no data is available, the classifications have been changed. In the updated system the classification starts with NO DATA and is followed by a short explanation for the data absence.

UNCLEAR was used as an 'interpreted_gas_show' classification in three wells (A08-01, E13-02 and G16-05) and is obsolete in the new classification system. A08-01 and E13-02 have been reviewed successfully and the UNCLEAR classifications have been replaced by GOOD, FAIR, POOR and NO SHOW ratings. G16-05 showed a very unlikely repeating pattern on the mudlog between 1050 m and 1320 m. Therefore, the classification has been changed to 'NO DATA part gaslog incorrect/absent'. The boreholes for which the 'interpreted_gas_show' was given a "0" classification have not been investigated yet and this is described in the updated classification.

Table 2.1: Refining 'log data' gas show and oil show classifications

Previous classification	Updated classification
GOOD	GOOD
FAIR	FAIR
POOR	POOR
OIL SHOW	OIL SHOW (only used for unrated oil occurrences)
NO SHOW	NO SHOW
SIDETRACK	NO DATA sidetracked
NO DATA	NO DATA part gaslog useless/absent
NO DATA/REVIEW	NO DATA entire gaslog useless/absent
NO STRAT	NO DATA no stratigraphy available
CONFIDENTIAL	NO DATA confidential
UNCLEAR	*Obsolete*

0	Not yet investigated

2.3.2 Refining ‘Test data’ HC show classifications

The ‘Test data’ spreadsheet describes the HC results from DST’s and RFT samples. Table 2.2 shows the previous and updated classifications used to describe DST results. The updated classification system used in the ‘Test data’ and ‘Log data’ spreadsheets are uniform. DST flow rates are given a GOOD, FAIR or POOR rating depending on the net HC flow rate. Indistinct classifications that do not quantify the HC result, such as OIL/MUD, have become obsolete. Also, several non HC indicators that describe the same DST result have been grouped under one classification.

Table 2.2: Refining ‘Test data’ DST classifications

Previous classification	Nr. of occurences	Updated classification	Nr. of occurences
GAS *(Net gas flow rate (m^3/d) > 50.000)*	110	GOOD *(Net gas flow rate (m^3/d) > 50.000)*	119
INSUFFICIENT GAS *(Net gas flow rate (m^3/d) < 50.000)*	20	FAIR *(10.000 < Net gas flow rate (m^3/d) < 50.000)*	7
		POOR *(1 < Net gas flow rate (m^3/d) < 10.000)*	13
OIL *(Net oil flow rate (m^3/d) > 10)*	18	GOOD *(Net oil flow rate (m^3/d) > 10)*	18
INSUFFICIENT OIL *(Net oil flow rate (m^3/d) < 10)*	11	FAIR *(1 < Net oil flow rate (m^3/d) < 10)*	11
		POOR *(0,1 < Net oil flow rate (m^3/d) < 1)*	3
OIL/MUD	3	*Obsolete*	
OIL/WATER	1	*Obsolete*	
NO FLOW/TIGHT/DRY	20	NO FLOW	20
WATER/BRINE/MUD	41	WATER	41
UNCLEAR	5	*Obsolete*	
Data missing, other reasons	2	NO DATA	2

Table 2.3 shows the previous and updated classifications for RFT sample results. Because RFT samples are foremost used to measure formation pressures its results are not accurate enough to be rated uniformly with ‘Log data’ and DST’s. In addition, RFT samples contain only a small amount of fluid which is not representative for the reservoir fluid. Furthermore, the fill time of most RFT samples is unknown so the reservoir properties are not measured. Therefore, the HC show cannot be rated and only the dominant phase of a RFT sample can be determined. Again, indistinct classifications in which the HC result is not quantified have become obsolete and several non HC indicators that describe the same RFT sample result have been grouped.

Table 2.3: Refining 'Test data' RFT classifications			
Previous classification	Nr. of occurences	Updated classification	Nr. of occurences
GAS	34	GAS major (*gas cut > 90%)*	26
		GAS minor (*gas cut < 90%)*	11
OIL	8	OIL major (*oil cut > 10%)*	16
		OIL minor (*oil cut < 10%)*	6
MUD/GAS	1	*Obsolete*	
OIL/MUD	3	*Obsolete*	
OIL/WATER	6	*Obsolete*	
OIL/BRINE	2	*Obsolete*	
NO FLOW/TIGHT/DRY	4	NO FLOW	3
WATER/BRINE/MUD	31	WATER	27
UNCLEAR	2	*Obsolete*	
SEAL FAILURE, DATA missing, other reasons	2	NO DATA	2

Table 2.4 shows the previous and updated classifications for boreholes in which no DST or RFT sample has been taken. The classifications have been changed to NO DATA followed by a short explanation indicating the reason for the data absence.

Table 2.4: Refining 'Test data' no test classifications			
Previous classification	Nr. of occurences	Updated classification	Nr. of occurences
NO DATA	216	NO DATA no test	216
SIDETRACK	76	NO DATA no test, sidetracked	76
CONFIDENTIAL	23	NO DATA confidential	23
REVIEW	1	*Obsolete*	

2.3.3 Refining '(SW-)core Data' HC show classifications

Table 2.5 shows the classifications that have been changed in the '(SW-)core Data' spreadsheet. Changes were only made to the classification system to clarify why no data is available. Again, these classification have been changed to the NO DATA annotation followed by a short explanation.

The two OIL SHOW classifications were not according to the workflow and have been changed to a POOR (L02-01) and FAIR (L02-03) rating. The seven (sw-)cores (obtained from three boreholes, A16-01, E13-02 and E16-02-S2) that were classified as REVIEW had French (sw-)core descriptions. In A16-01 and E16-02-S2 POOR oil shows were recognized. The (sw-)core descriptions from E13-02 were illegible and have been given a NO DATA classification.

Table 2.5: Refining '(SW-)core data' classifications for cores and sidewall cores			
Previous classification	Nr. of occurrences	Updated classification	Nr. of occurrences

OIL SHOW	2	*Not according to the workflow*	0
GOOD	35	GOOD	35
FAIR	57	FAIR	58
POOR	62	POOR	65
NO SHOW	421	NO SHOW	423
Other reason NO DATA	0	NO DATA	3
NO DATA	189	NO DATA no (sw-)core	189
CONFIDENTIAL	31	NO DATA confidential	31
REVIEW	7	*Obsolete*	0
SIDETRACK	70	NO DATA sidetracked	70

2.4 Updating the HC shows Workflow and extending the ATLAS

The third version of the HC show Workflow can be seen in Appendix A. This version of the Workflow is up to date with all the changes described in the previous sections. However, 'To decide whether a gas show is 'GOOD' or 'POOR' i.e., whether or not a significant hydrocarbon accumulation is indicated, requires a total evaluation of all mudlogging parameters plus consideration of the many variable system conditions' (Yassin, 2012). Thus, the most important factor for classifying HC shows will always be the analyst's interpretation and petrophysical and geological knowledge.

The HC Show Interpretation ATLAS which contains interpretation examples for the HC shows database has also been extended with two chapters. The latest version can be found in Appendix C.

2.5 Exceptional borehole classifications

As mentioned above, user interpretation is key when classifying HC shows. Here a few examples will be described in which HC shows could not be classified by following the HC shows Workflow.

2.5.1 French abbreviations used in mudlogs

In French logs the abbreviations AF, BF and BRC are often used, as can be seen in Figure 2.2 and Figure 2.3. The meaning of these abbreviations could not be traced back. Peaks labeled with BRC or AF do not correspond to lithological changes and look like artificial gas peak. Therefore, gas peaks labeled with BRC or AF will be ignored. From the examples above and other examples it appears that BF is the French abbreviation for Total Gas. Consequently, if the highest gas peak in a stratigraphy is annotated with BF it will be documented in the HC shows database.

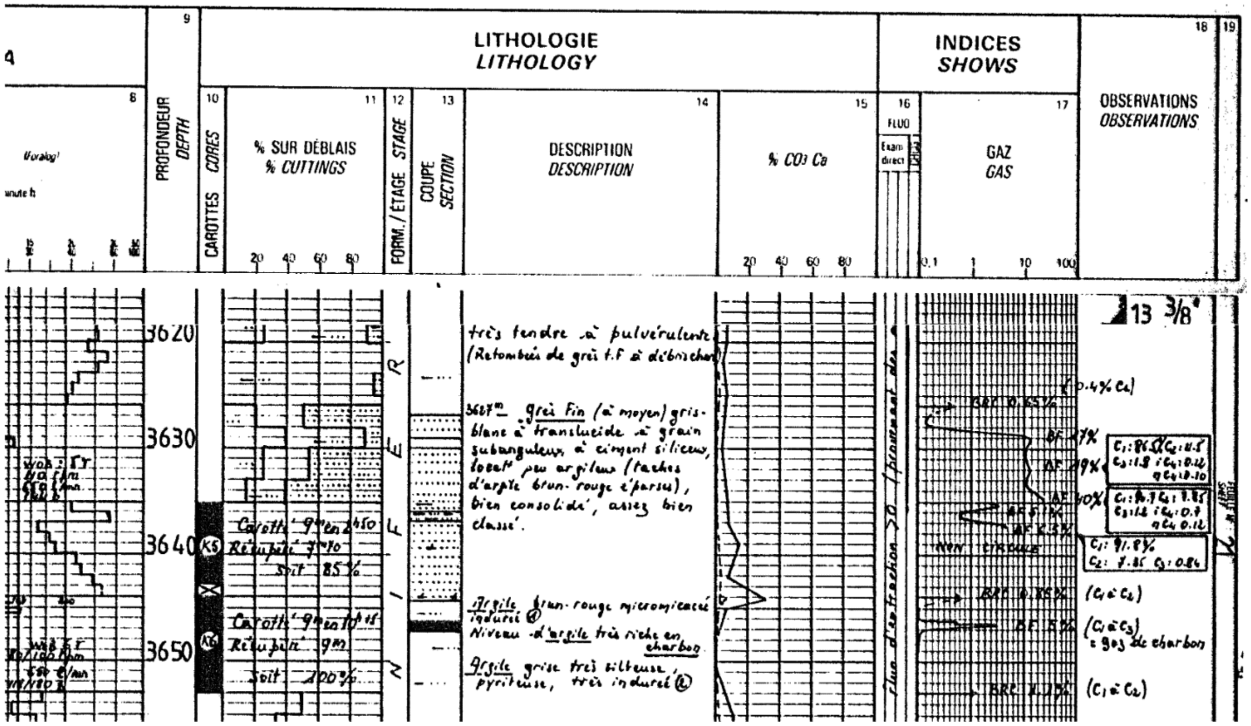

Figure 2.2: Part of the mudlog belonging to borehole L04-B-01 in which the abbreviations AF, BF and BRC are used.

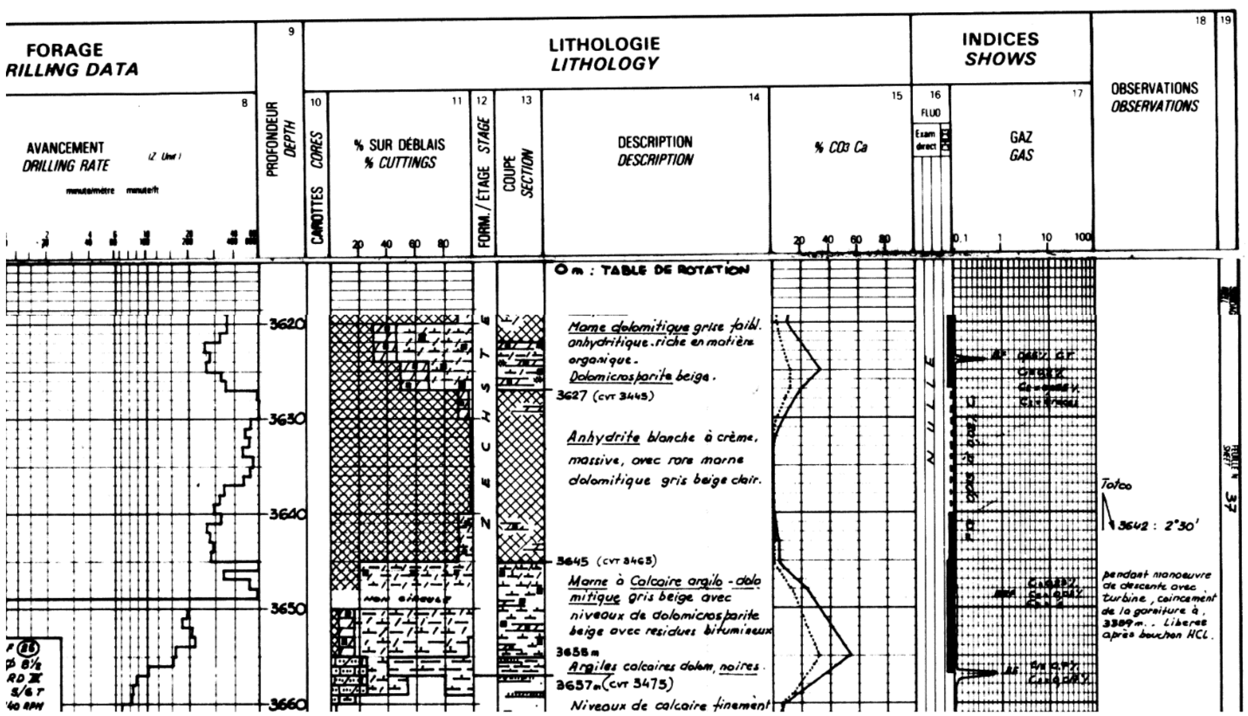

Figure 2.3: Part of the mudlog belonging to borehole L04-A-04 in which the abbreviation AF is used.

2.5.2 Incorrect TNO defined stratigraphy

The TNO defined Zechstein stratigraphy for borehole L05-06 and several other boreholes does not correspond to the composite log and the formation evaluation log. Figure 2.4 shows part of the composite log. The green lines indicate the TNO defined stratigraphy whereas the red lines show the stratigraphy that I have used for my analysis. The red lines in the figure agree better with the described stratigraphy, gamma ray results and graphic lithology. The changes that have been made to the HC shows database are shown in Table 2.6 and Table 2.7.

Table 2.6: TNO defined stratigraphy (green)

Stratigraphic code	Top layer	Bottom layer	Depth gas peak	Interpreted gas show
ZESA	690	4400,5	4398	POOR
ZEZ2A	4400,5	4406		NO SHOW
ZEZ2C	4406	4412,5		NO SHOW
ZEZ1W	4412,5	4440	4430	POOR
ZEZ1C	4440	4444		NO SHOW
ZEZ1K	4444	4444,5		NO SHOW

Table 2.7: New stratigraphy (red)

Stratigraphic code	Top layer	Bottom layer	Depth gas peak	Interpreted gas show
ZESA	690	4357		NO SHOW
ZEZ2A	4357	4391		NO SHOW
ZEZ2C	4391	4416	4398	POOR
ZEZ1W	4416	4425		NO SHOW
ZEZ1C	4425	4444	4430	POOR
ZEZ1K	4444	4444,5		NO SHOW

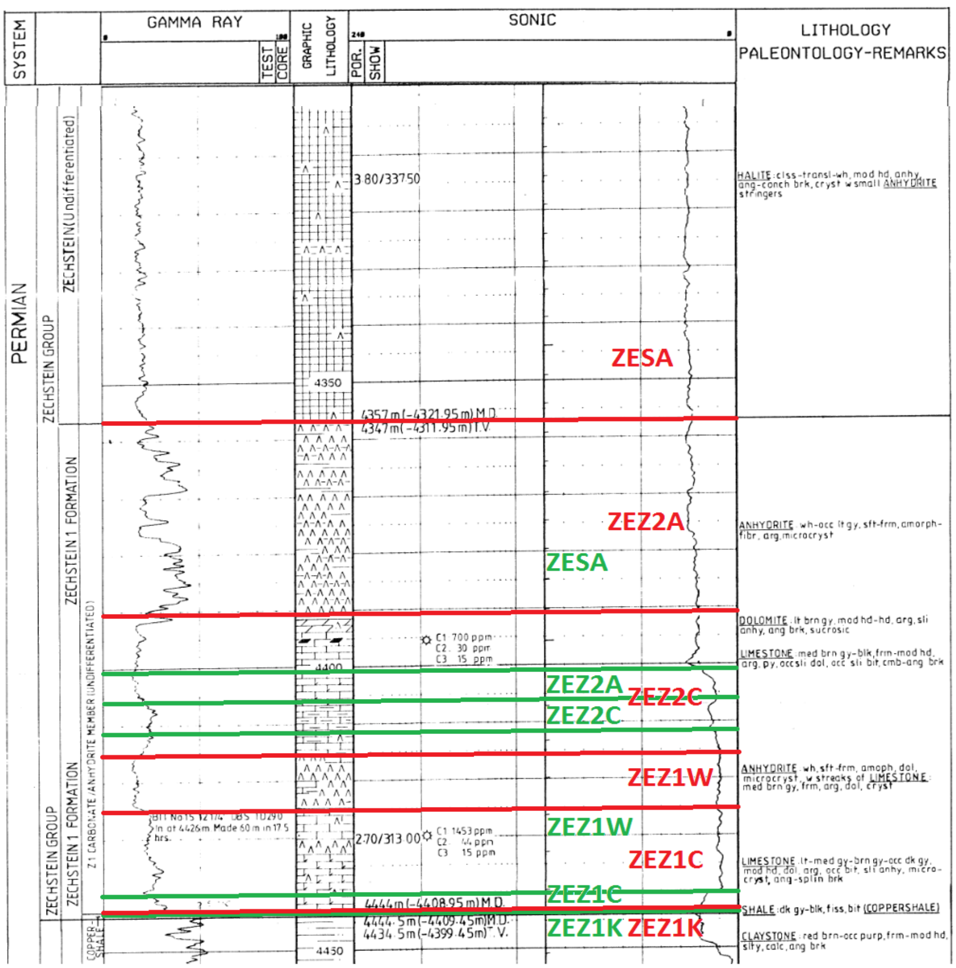

Figure 2.4: The TNO defined stratigraphy (red lines) of L05-06 appear to be incorrect. The stratigraphy indicated by the green lines has been used in the HC shows database.

2.5.3 No TNO defined stratigraphy for confidential borehole L02-09

Borehole L02-09 has been drilled recently and is still confidential. For this reason no TNO stratigraphy is available. The stratigraphic layers recognized in this borehole have been described on the mudlog and this stratigraphy is used in the HC shows database.

2.5.4 Unknown gas/water and oil/water ratios in RFTs

RFT samples are given a classification based on the dominant phase that is present in the sample (see section 2.3.2). For boreholes F17-07, G16-01, L02-07, L05-03, L05-10, L05-11 and L06-B-01-S2 either the gas/water or oil/water ratio is not known, therefore, the dominant phase could not be determined. To make sure that no good shows are missed in the HC shows database, these RFTs have been given GAS major or OIL major classifications.

3 Results

3.1 Comparing interpreted gas shows to raw gas shows

Interpreted gas shows are dependent on peak gas readings, the ratio between peak gas and background gas (PtBR), the rock type, the composition, grading and the thickness of a rock layer (see Table 3.1). The lithology variables are subject to user interpretation and often downgrade a classification (e.g. a good gas reading in a claystone results in a poor gas show). The primary goal of the HC shows database is to map all good oil and gas shows. To make sure no good shows are lost due to user interpretations a raw gas show column has been added to the datasheet. The raw gas show is only dependent on the peak gas reading, and the PtBR (see Table 3.1). Hence, it is less sensitive to user interpretation and can be utilized to identify misinterpreted gas shows in the HC shows datasheet.

Table 3.1: Difference between raw and interpreted gas shows

			NO SHOW	POOR	FAIR	GOOD
Interpreted	raw	Peak gas	< 500ppm (0,05%)	> 500ppm (0,05%)	> 500ppm (0,05%)	> 1000ppm (0,1%)
		PtBR	< 2	2 < PtBR < 3	> 3	> 5
		Lithology & composition/grading & thickness	Halite	mudstone/shale/ claystone/marl	siltstone	sandstone/ limestone/chalk

The graph in Figure 3.1 shows a cross correlation between the interpreted and raw gas show classifications per stratigraphy in the HC show database before analysis. If the interpreted and raw gas shows have the same classification, the show is colored green. The circles in yellow illustrate gas shows that have classifications that are one rating apart. The orange and red circles represent gas show ratings that are respectively two and three ratings apart.

Gas shows that have an ‘interpreted_gas_show’ rating that is higher than its ‘raw_gas_show’ rating are unlikely because the lithological interpretation can only downgrade show classifications. Thus, all the stratigraphies above the ‘green line’ have been revisited. Special attention should be paid to uncommon occasions (e.g. well flows and very high peak and background gas readings). The number of shows that

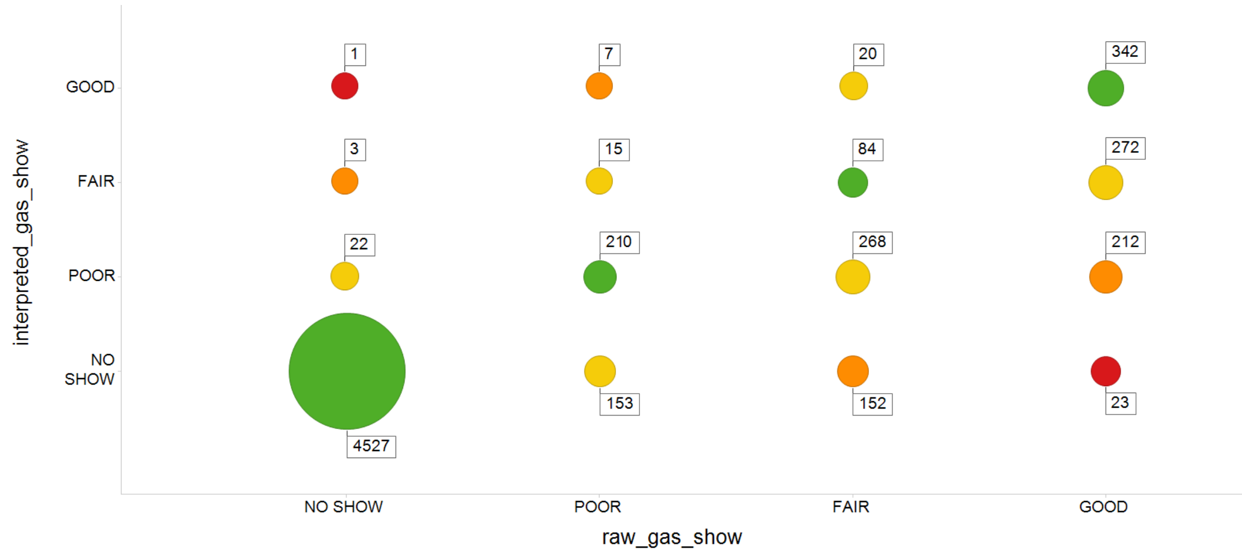

Figure 3.1: The interpreted and the raw gas show ratings for all stratigraphies in the HC shows database before analysis.

are still present above the 'green line' after the analysis is shown in Figure 3.2. The reasons for their deviating ratings are explained in Appendix D.1.

Shows that have a higher 'raw_gas_show' rating than 'interpreted_gas_show' rating (below the 'green line') often have a poor reservoir lithology which downgrades the 'interpreted_gas_show' rating. Here we will consider the stratigraphies that have a GOOD 'raw_gas_show' rating, a NO SHOW 'interpreted_gas_show' rating. Shows with a halite, salt or anhydrite lithology are not revisited because the lithology explains the NO SHOW 'interpreted_gas_show' ratings. The gas shows with a GOOD-NO SHOW rating that have been revisited in this study are shown in Appendix D.2. In three cases the 'interpreted_gas_show' ratings have been changed from NO SHOW to POOR (compare Figure 3.1 and Figure 3.2).

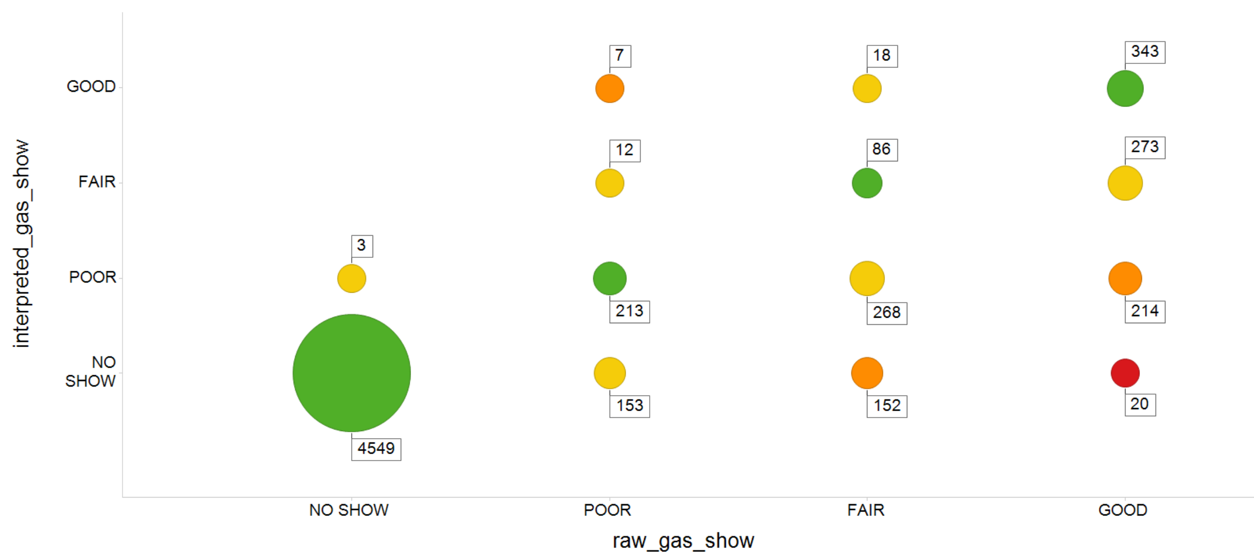

Figure 3.2: The interpreted and the raw gas show ratings for all stratigraphies in the HC shows database after analysis.

The most common lithologies of the 212 gas shows in Figure 3.1 that have been identified by a GOOD 'raw_gas_show' and a POOR 'interpreted_gas_show' are a combination of claystone, mudstone, clay, shale, anhydrite, siltstone and/or marl. However, 36 stratigraphies contain shows that are found in chalk, dolomite, limestone, sand and/or sandstone. 13 of these shows contain more than 1950 ppm 'total_HC_gas' and are described in Appendix D.3. After analysis the 'interpreted_gas_show' rating of one show has been changed from POOR to FAIR. The other shows have POOR 'interpreted_gas_show' ratings for good reasons.

Most of the shows that have been rated as a FAIR 'raw_gas_show' and a NO SHOW 'interpreted_gas_show' have a too low 'total_HC_gas' value to be considered as missed pay. For this reason, these shows are ignored in this study.

3.2 Comparing the HC shows database to the Panterra MPA

In 2016 Panterra finished a missed pay analysis (MPA) covering 155 exploration wells located in the Dutch offshore. Most of the boreholes were given a 'dry' result by the operator, however, some boreholes were assigned a 'gas shows', 'gas', 'oil' or 'oil shows' result. Because some of these boreholes have been proven to contain HC shows or may contain missed pay it might be interesting to reconsider the producibility of these boreholes using recent technological inventions. The aim of this section is to find and describe the most promising HC shows by comparing the EBN HC shows database to the Panterra MPA for mutual occurrences of promising HC shows. Also, discrepancies between the datasets will be investigated. The Panterra MPA describes the best HC show in each TNO defined stratigraphic group. In contrast, the HC shows database makes use of a more detailed TNO stratigraphy and several HC shows can be described in a single stratigraphic group. From these shows the best show per stratigraphic group is selected and compared to the Panterra MPA.

Both datasets use different data types to identify and classify HC shows. Therefore, the datasets complement each other in finding the most promising HC shows. The Panterra MPA is based on an extensive analysis using Interactive Petrophysics which covers data from several sources, e.g. wireline logs, mudlogs, pressure data, well reports and core data. The HC shows database presents a more straightforward way to identify HC shows. It is based on mudlogs, lithology descriptions, DSTs, RFTs and (sw-)core data.

Table 3.2: Panterra MPA vs. HC shows database classification system

Panterra MPA Class / Ranking	Panterra MPA definition	Panterra MPA classifications translated to EBN HC shows database classification
1	Presence of HC proven by RFT samples / well tests; flow of HC	GOOD
2	Strong indications of presence HC; petrophysical/RFT pressure evidence + shows	FAIR
3	Substantial shows	FAIR
4	Few / minor shows	POOR
5	No indication of presence hydrocarbons	NO SHOW
6	Stratigraphic unit not present	NO DATA no stratigraphy available
7	Stratigraphic unit not drilled (reached)	*Stratigraphic unit not drilled (reached)*
8	Discovery well, now produced and abandoned	*Unnecessary*

The classification system used in the Panterra MPA is shown in the first column of Table 3.2. The third column shows the corresponding classification system as used in the HC show database. Note that the OIL SHOW classifications in the HC show database will be interpreted as POOR classifications. This is because most OIL SHOW shows have not been described in more detail due to a lack of observations which might indicate a POOR oil show. Also note that the Rot formation is not considered in the Panterra MPA. Thus, inter-database analysis for the Rot formation are not possible. The Rot formation is unlikely to contain significant HC shows because it is defined by sequences of interbedded silty, anhydritic claystones, anhydrite and rock-salt (Adrichem Boogaert & Kouwe, 1997).

From the 155 boreholes that have been analyzed by Panterra, 41 boreholes are also present in the HC shows database (Figure 3.3). The overlapping boreholes are all located in the northern half of the Dutch offshore (see Appendix E) and can be utilized for two purposes: to search for missed pay and as a QC on the HC shows database.

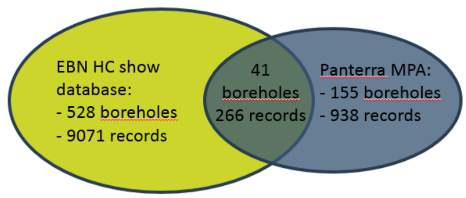

Figure 3.3: Number of boreholes and stratigraphic groups that are present in both the HC shows database and the Panterra MPA.

Figure 3.4 illustrates the number of stratigraphic groups that have similar and different show classifications in the HC shows database and the Panterra MPA. Most stratigraphic groups have been classified as a combination of no show and poor shows which means that these layers are very unlikely to contain significant HC reserves. The other shows in the graph are interesting for several reasons and should be analyzed individually. The stratigraphic groups that have been rated as a combination of fair and good in both studies are most likely to have a producible HC show. The orange and red circles indicate shows that HC shows were given a very different rating in both studies. These wells are interesting because they might indicate a misinterpretation or a missed HC show in either one of the studies.

Vis & Lutgert (2016) reviewed several wells from the Panterra MPA and concluded that some of the interpretations are too optimistic. Still, Figure 3.4 shows that the HC shows database is more optimistic than the Panterra MPA. Several HC shows that were interpreted as NO SHOW in the Panterra MPA have been given a POOR, FAIR or GOOD rating in the HC show database.

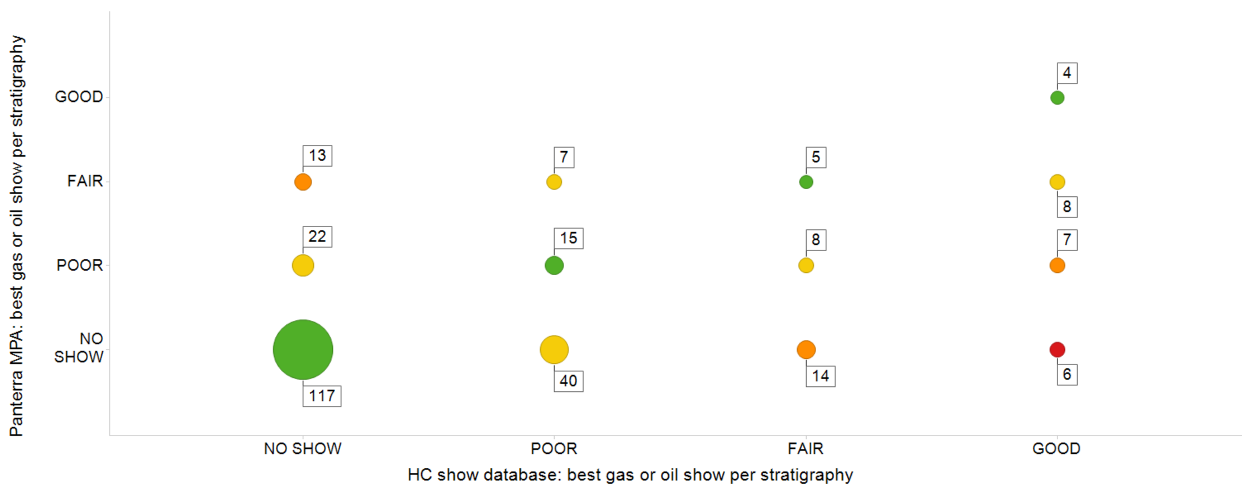

Figure 3.4: The best HC shows database show rating vs. the best Panterra MPA show rating per stratigraphic group. Green circles represent stratigraphic groups that have the same rating in both studies. Yellow circles indicate that the show classifications are one rating apart. Show ratings that are two or three ratings apart are plotted by respectively orange and red circles.

3.3 Regional source rock study

The thickness of Zechstein salt layers found in boreholes analyzed in the HC shows database ranges between 10s of meters to over 1 km. Because salt is a good reservoir seal, the following hypothesis will be tested in this study: does the thickness of Zechstein salts affect the location of gas shows in the northern Dutch offshore?

The best gas shows per borehole above and below the Zechstein salts are shown in respectively Figure 3.5a and Figure 3.5b. The background colors represent the thicknesses of the Zechstein salts as described by the DGM-diep V3 model (Nlog, 2012). Figure 3.5a shows that most fair and good gas shows above the Zechstein salts are located in the Step Graben, Central Graben, Schill Grund High and the Terschelling Basin. These structural elements typically have Zechstein Group thicknesses ranging between 0 and 300 m. In contrast, Figure 3.5b shows that the Cleaverbank High in the west and the very eastern structural elements of the Dutch offshore show mainly fair and good shows below the Zechstein Group. In these areas the Zechstein Group is over 700 m thick. So, there appears to be a relationship between the thickness of Zechstein salts and the locations of HC shows.

However, towards the south of the L quadrant the locations of the gas shows shift from above to below the Zechstein salts. This shift in gas show depth corresponds with the change from the Central Graben to the Central Offshore Platform. Therefore, the location of gas shows is likely to be the result of the type of source rock. In the grabens and basins Posidonia shales have been deposited in the Lower Jurassic. In contrast, Jurassic and Triassic rocks are absent or very thin on the platforms and highs (see Appendix F). In these areas the source rocks are Westphalian coal seams (Fattah, Verweij, Witmans, & ten Veen, 2012).

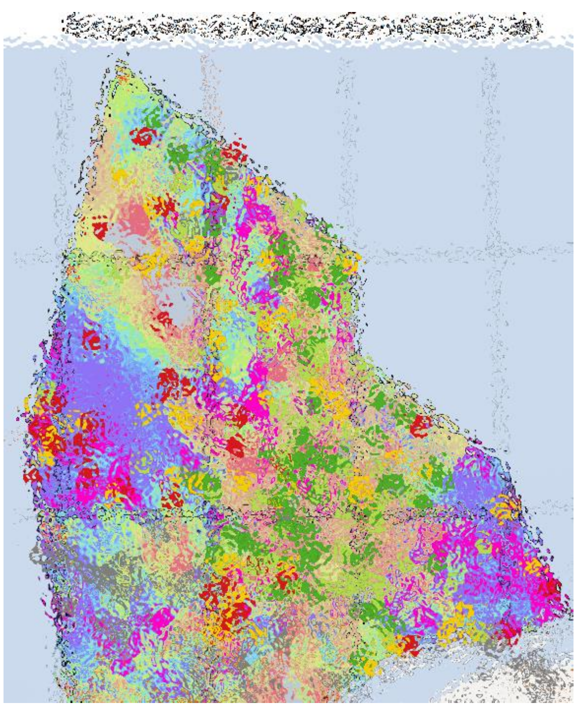

Figure 3.5a: Best gas shows per borehole above the Zechstein salts. The background color represents the Zechstein salt thickness.

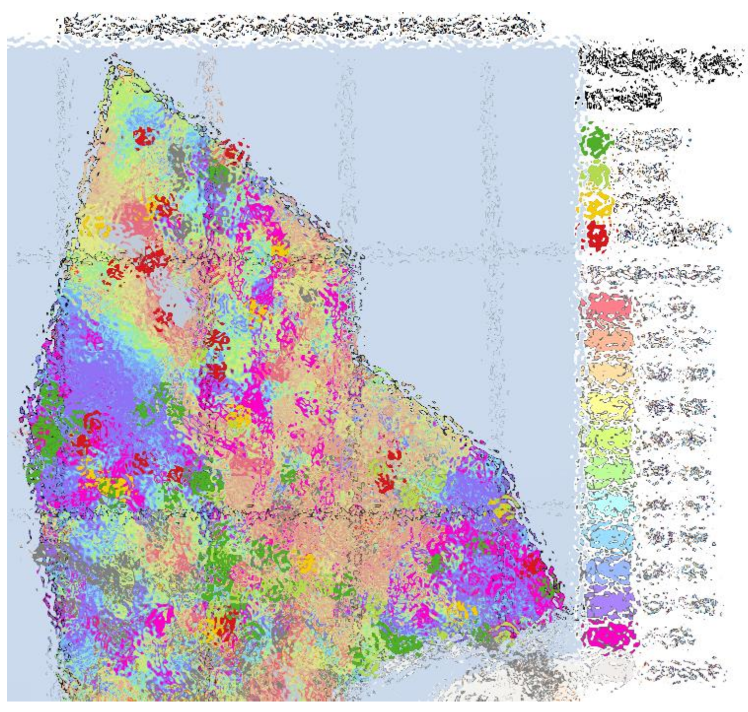

Figure 3.5b: Best gas shows per borehole below the Zechstein salts. The background color represents the Zechstein salt thickness.

Figure 3.6 shows the number of classifications per stratigraphic groups in the entire HC shows database. Some layers are more likely to contain good HC shows than other layers. Also, in over half of the cases that the Limburg group was drilled for, gas shows were encountered. In 25 percent of the boreholes that reached the Limburg group a GOOD show was found. Thus, the Limburg group is only drilled for good reasons. Note that the N stratigraphy is only used when the North Sea Supergroup is not defined in more detail.

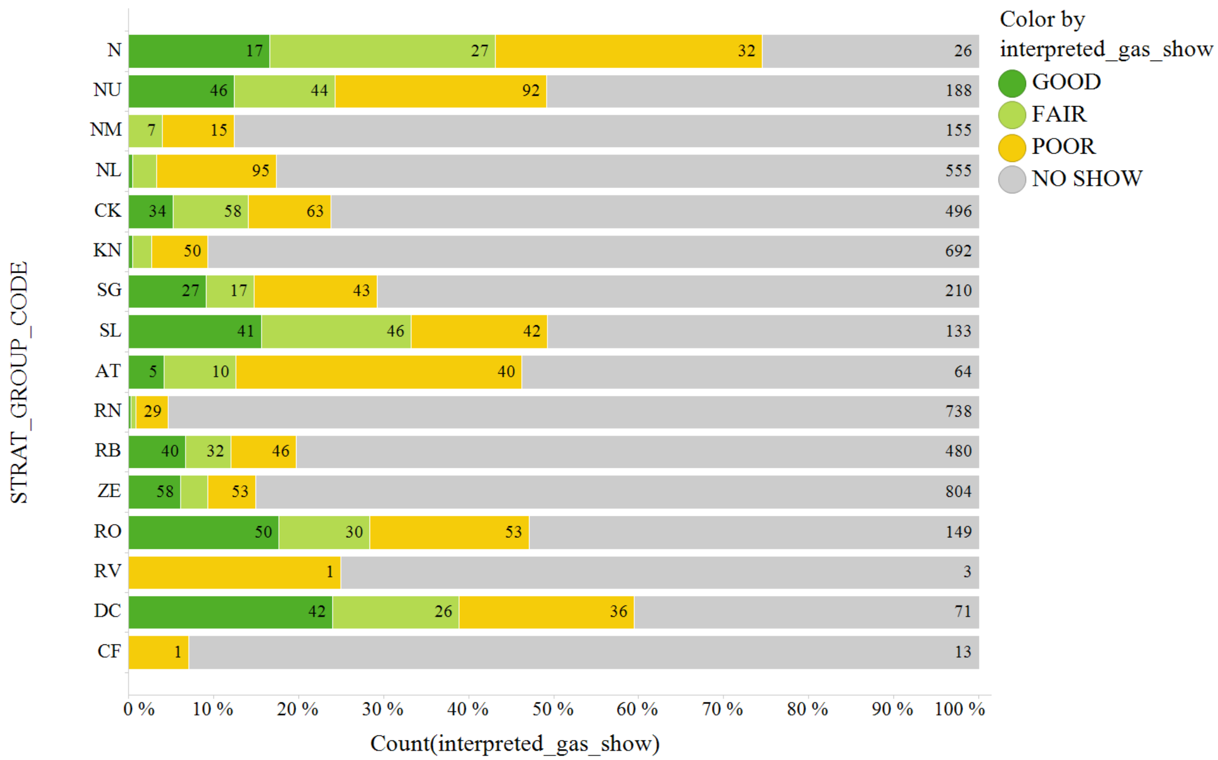

Figure 3.6: Nr. of show classifications per stratigraphic group.

3.4 The effect of mud type on gas readings

Oil based drilling mud (OBM) is known to produce toxic fumes. For this reason, many offshore rigs use polymer/synthetic oil based drilling mud (PBM), e.g. Low Toxicity Oil Based Mud (LTOBM) (Simpson & Keen, 2006). The fumes of drilling fluids also enter the gas chromatograph and possibly affect its readings. The aim of this study was to find and, if possible, quantify the effect that mud types (especially OBM) have on gas readings. The three mud types described in this study are OBM, PBM and water based mud (WBM). The mud types represented by the 'UNKNOWN TYPE' label could not be placed in one of the mud type groups. The 'NOT SPECIFIED label represents all the cases in which the mud type was not specified.

For each mud type Table 3.3 and Table 3.4 show respectively the mean total gas and its standard error and the mean background gas and its standard error. Both the mean total gas and the mean background gas are highest for OBM and WBM. From the three mud types PBM has the lowest gas readings. Strangely the mud types that are labeled by 'UNKOWN TYPE' and 'NOT SPECIFIED' have an even lower mean total and mean background gas.

The standard errors indicate how far the values deviate from the mean value. A large standard error indicates that the values vary a lot. OBM has the largest standard error which means that some very high values contribute to the high mean values. Background gas has a low standard error because its values do not fluctuate as much as peak gas values.

Table 3.3: The effect of mud type on the 'total_HC_gas'			
Mud type	Nr. of occurrences	Mean 'total_gas_ppm'	Standard error of the 'total_gas_ ppm'
OBM	414	19728.69	2770.29
WBM	751	17960.87	2125.34
PBM	907	13790.19	1706.19
UNKNOWN TYPE	554	9481.63	1223.64
NOT SPECIFIED	51	4195.37	710.38

Table 3.4: The effect of mud type on the 'background_gas'			
Mud type	Nr. of occurrences	Mean 'background_gas_ppm'	Standard error of the 'bacground_gas_ppm'
OBM	826	8763.35	292.01
WBM	1191	8697.13	233.60
PBM	1573	5965.50	247.00
UNKNOWN TYPE	52	4106.96	198.98
NOT SPECIFIED	646	3879.67	154.38

3.5 Proofing the 'Excel deviatie tool'

To be able to visualize well trajectories a column with the along hole (AH) depths of gas shows (AH_depth_gas) was added to the HC shows database. A combination of the AH depths and borehole name can be used to acquire the borehole 'easting' and 'northing' when updating the GISbase. This method was first tried in the HC shows datasheet. At the same time the stratigraphies found by the 'EXCEL deviatie tool' were compared to the stratigraphies in the HC shows database. The results from this study (29th of November, 2016) are described below.

User input errors (corrected)

- 34 mismatches were caused by typos or values entered on the wrong line.
- 11 mismatches had an unclear origin.
- 4 boreholes, with POOR gas show classifications, were missing an 'exact_measurement_ depth_gas'.
- 1 POOR gas show reading without depth measurement has been changed to a NO SHOW classification.
- 1 mismatch was a duplicate error of a sidetrack.
- 1 stratigraphic layer code ('STRAT_CODE') has been added to the datasheet (G17-S-01).

Mismatches between the HC show database stratigraphy and the 'Excel deviatie tool stratigraphy' are described below:

- 76 cases are caused by a mismatch concerning the Upper Jurassic SLCxx and SGxxx members.
- 5 cases are caused by a mismatch concerning the Lower Cretaceous KNxxx members.
- 29 cases are located on a fault, FLT-R or FLT-N in the HC shows database stratigraphy. No faults are used in the 'EXCEL deviatie tool'. Reviewed with Peter Bange.
- 10 mismatches, all concerning borehole G16-03, show a discrepancy between the stratigraphies. Reviewed with Peter Bange.
- 7 boreholes were not given any coordinates or TVD below a certain depth. The error displayed in the 'EXCEL deviatie tool' was 'Max depth exceeded'. Reviewed with Peter Bange.
- 7 boreholes were duplicated by the 'EXCEL deviatie tool' causing several rows to move down. Reviewed with Peter Bange.
- 26 mismatches are the result of a gas show being located exactly on a stratigraphic boundary.

From the results described above we can conclude that the 'EXCEL deviatie tool' works properly, except for the SLCxx, SGxxx and the KNxxx formations and members. These mismatches are probably caused by a recent reevaluation of the Lower Cretaceous and Upper Jurassic stratigraphies.

3.6 Spotfire QC and implementing an user input check

An extensive spotfire QC was performed on the HC show database to find errors (e.g. missing HC show classifications, typos, missing depth measurements, missing lithologies etc.). Also inconsistent HC show classifications and parameters which describe only a few shows were identified and changed to a more general HC show description (e.g. "NO SHOW / NOT CLEAR", "%<space>" to "%", "ppm<space>" to "ppm", "kppm" to "ppm" etc).

The Spotfire QC and the QC performed with the 'EXCEL deviatie tool' resulted in a list of common errors. Table 3.5 describes the error indicators, gives a short description of the error and states the number of occurrences before the check and after correction.

Table 3.5: Number of errors found by the 'user_input_check'

Error indicator	Error description	Nr. of occurrences before checking	Current number of occurrences
FALSE1	Confirm STRAT_BASISLAAG_AH < exact_depth_measurement_gas < STRAT_TOPLAAG_AH	23 (+34 described in section 3.5)	1
FALSE2	Confirm STRAT_BASISLAAG_AH < exact_depth_measurement_oil < STRAT_TOPLAAG_AH	10	0
FALSE3	Confirm exact_depth_measurement_gas has been entered when interpreted_gas_show is GOOD, FAIR or POOR	5	0
FALSE4	Confirm exact_depth_measurement_oil has been entered when oil_show is GOOD, FAIR or POOR	7	0
FALSE5	Confirm no exact_depth_measurement_gas has been entered when no data is available	4	0

FALSE6	Confirm no exact_depth_measurement_oil has been entered when no data is available	0	0
FALSE7	Confirm total_HC_gas > background_gas	11	0
FALSE8	Confirm gas_unit is % when needed	0	0
FALSE9	Confirm gas_unit is ppm when needed	0	0
FALSE10	Confirm no GOOD reading has total_HC_gas < 1000 ppm or total_HC_gas < 0,1 %	2	1
FALSE11	Confirm no POOR or FAIR reading has total_HC_gas < 500 ppm total_HC_gas < 0,05 %	11	0
FALSE12	Confirm lithology has been entered when an exact_depth_measurement_gas is given	36	0
FALSE13	Confirm lithology has been entered when an exact_depth_measurement_oil is given	16	0
FALSE14	exact_depth_measurement_gas, total_HC_gas and background_gas are numbers and larger than 0	32	32

The current number of occurrences larger than zero are explained below:

- The FALSE1 error indicator is caused by a depth reading falling inside the log, but outside the TNO stratigraphy (M01-03). Probably the TNO stratigraphy is incorrect.
- The FALSE10 error indicator is caused by a peak corresponding to a well flow (E13-02).
- The 32 FALSE14 error indicators are all caused by the gaslog of borehole G17-01 having no scale. From other sources and very high PtBR peaks we know this borehole has GOOD shows and for this reason it has not been discarded.

3.7 GISbase requires a number or text format per column

The amount of measured hydrocarbon gases (e.g. methane, ethane, iso-propane, n-propane etc) is documented in the HC shows database. Not all types of gas are measured in each borehole, e.g. either the total amount of propane is measured or the amounts of iso- and n-propane are measured. If a type of gas is not measured in a borehole, this gas type is annotated with 'NOT MEASURED' in the datasheet. As a result these columns may contain both numbers and text strings.

This mix up of numbers and text strings poses no problems in Excel. However, when the datasheet is exported to the GISbase (in MS Access format) each column is given a text or number format (CREATE TABLE table_name[column1 **text**, column2 **integer**, ...]). If a column starts with several numbers, the column is given a number format and text strings in this column (the 'NOT MEASURED' annotations) will be ignored resulting in empty cells. In contrast, if a column starts with several text strings, both numbers and text strings will be read into the database. This produces an inconsistent database layout as shown in Figure 3.7 where the red squares should contain the 'NOT MEASURED' annotations. Inconsistencies in the database may cause errors in straightforward analyses.

Several combinations of formats (general, text and number) have been used for to the relevant columns in MS Excel. However, no combination of formats removed the inconsistencies from the database. To improve the database quality these inconsistencies should be removed. This can be achieved by replacing the 'NOT MEASURED' annotations with either a negative number or a blank cell.

borehole	STRAT_CODE	exact_measur...	interpreted_ga...	total_HC_gas	background_g...	C1_max	c2_max	C3_Max	c4_max	iC4_max	nC4_max	C5_max	iC5_max	nC5_max
A05-01	NO STRAT		NO DATA no str...											
A08-01	NU	610,00	FAIR	73339,00	20000,00	73339,00	0,00	0,00	NOT MEASURED	0,00	0,00	0,00	NOT MEASURED	NOT MEASURED
A08-01	NMRF	1466,00	NO SHOW	5325,00	3000,00	5525,00	0,00	0,00	NOT MEASURED	0,00	0,00	0,00	NOT MEASURED	NOT MEASURED
A08-01	NLFFY	1685,00	NO SHOW	7957,00	3000,00	7957,00	0,00	0,00	NOT MEASURED	0,00	0,00	0,00	NOT MEASURED	NOT MEASURED
A08-01	NLFFT	2470,00	NO SHOW	4800,00	2000,00	4923,00	0,00	0,00	NOT MEASURED	0,00	0,00	0,00	NOT MEASURED	NOT MEASURED
A08-01	NLLF	2487,00	NO SHOW	4923,00	2000,00	800,00	0,00	0,00	NOT MEASURED	0,00	0,00	0,00	NOT MEASURED	NOT MEASURED
A08-01	CKEK	2575,00	NO SHOW	1623,00	600,00	1623,00	0,00	0,00	NOT MEASURED	0,00	0,00	0,00	NOT MEASURED	NOT MEASURED
A08-01	CKGR	2750,00	NO SHOW	361,00	250,00	361,00	0,00	0,00	NOT MEASURED	0,00	0,00	0,00	NOT MEASURED	NOT MEASURED
A08-01	CKTX	3095,00	NO SHOW	335,00	200,00	335,00	0,00	0,00	NOT MEASURED	0,00	0,00	0,00	NOT MEASURED	NOT MEASURED
A08-01	KNGL	3125,00	NO SHOW	200,00	200,00	511,00	0,00	0,00	NOT MEASURED	0,00	0,00	0,00	NOT MEASURED	NOT MEASURED
A08-01	SGKI	3250,00	NO SHOW	1370,00	1000,00	800,00	60,00	50,00	NOT MEASURED	5,00	0,00	0,00	NOT MEASURED	NOT MEASURED
A08-01	SLC	3290,00	GOOD	13388,00	1000,00	10100,00	1050,00	310,00	NOT MEASURED	120,00	90,00	0,00	NOT MEASURED	NOT MEASURED
A08-01	RB	3304,00	POOR	14560,00	5000,00	13000,00	500,00	500,00	NOT MEASURED	300,00	200,00	60,00	NOT MEASURED	NOT MEASURED
A08-01	ZECP	3309,00	NO SHOW	6700,00	3000,00	4500,00	900,00	600,00	NOT MEASURED	400,00	200,00	100,00	NOT MEASURED	NOT MEASURED
A08-01	ZESA		NO SHOW	0,00	3000,00	0,00	0,00	0,00	NOT MEASURED	0,00	0,00	0,00	NOT MEASURED	NOT MEASURED
A11-01	N	1855,00	NO SHOW	0,70	0,50				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	CKEK		NO SHOW	0,00	0,60				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	CKGR		NO SHOW	0,00	0,40				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	KNGLU		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	SGKI		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	RBSHM		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEUC		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ4H		NO SHOW	0,00	0,20				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ4A		NO SHOW	0,00	0,20				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ4R		NO SHOW	0,00	0,20				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ3H	3225,00	NO SHOW	0,30	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ3B		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ3G		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ2T		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ2H		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ2A		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ2C		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ1W		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ1C		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ZEZ1K		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	ROCL		NO SHOW	0,00	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A11-01	DCGM	3710,00	NO SHOW	0,50	0,10				NOT MEASURED				NOT MEASURED	NOT MEASURED
A12-01	N	905,00	FAIR	40000,00	3000,00	40000,00	200,00	70,00	0			0,00	NOT MEASURED	NOT MEASURED
A12-01	CKEK	2040,00	NO SHOW	900,00	200,00	900,00	0,00	0,00	0			0,00	NOT MEASURED	NOT MEASURED
A12-01	CKGR		NO SHOW	0,00	300,00	0,00	0,00	0,00	0			0,00	NOT MEASURED	NOT MEASURED
A12-01	KNGLU		NO SHOW	0,00	300,00	0,00	0,00	0,00	0			0,00	NOT MEASURED	NOT MEASURED
A12-01	SGKI	2735,00	POOR	600,00	100,00	600,00	120,00	110,00	10			0,00	NOT MEASURED	NOT MEASURED
A12-01	SLCM	2792,00	POOR	900,00	200,00	900,00	200,00	100,00	20			0,00	NOT MEASURED	NOT MEASURED
A12-01	ZESA	3360,00	NO SHOW	600,00		600,00	0,00	0,00	0			0,00	NOT MEASURED	NOT MEASURED

Figure 3.7: Incorrect database layout as a result of wrong column formats in the GISbase. The red squares should contain the 'NOT MEASURED' annotations.

3.8 Correlating mudlog data to DST and RFT results

The HC shows database consists of mudlog data, test data and core data. These three independent data sources allow for an intra-database QC. Kickken, 2016 found a positive correlation between the phases (gas and oil) obtained from DST results and 'Log data'. In this study we will extend this analysis by considering the ratings (GOOD, FAIR and POOR) that have been given to DST's. In addition, we will extend the QC by considering the correlation between RFT's and 'Log data'. Based on its result we will advise on the refined DST and RFT classification system in the discussion. Note that the best 'Log data' show in the target stratigraphy of a DST will be compared to the DST result. Therefore, the show may be located out of the DST depth interval. Likewise, the best HC show in the stratigraphy in which an RFT was taken will be compared to the RFT result.

Figure 3.8 shows the number of DST's which resulted in a non-oil result. The bar colors represent the 'interpreted_gas_show' rating from the 'Log data'. In 95% of the DST's in which gas was found the 'Log data' also indicated a gas show. If the DST's for which no mudlog data is available are ignored, 70.6% of the good rated DST's correspond with a good show in the DST target stratigraphy. Also, over half of the DST's in which no HCs were found correspond with a stratigraphy in which no gas shows were found on the mudlog.

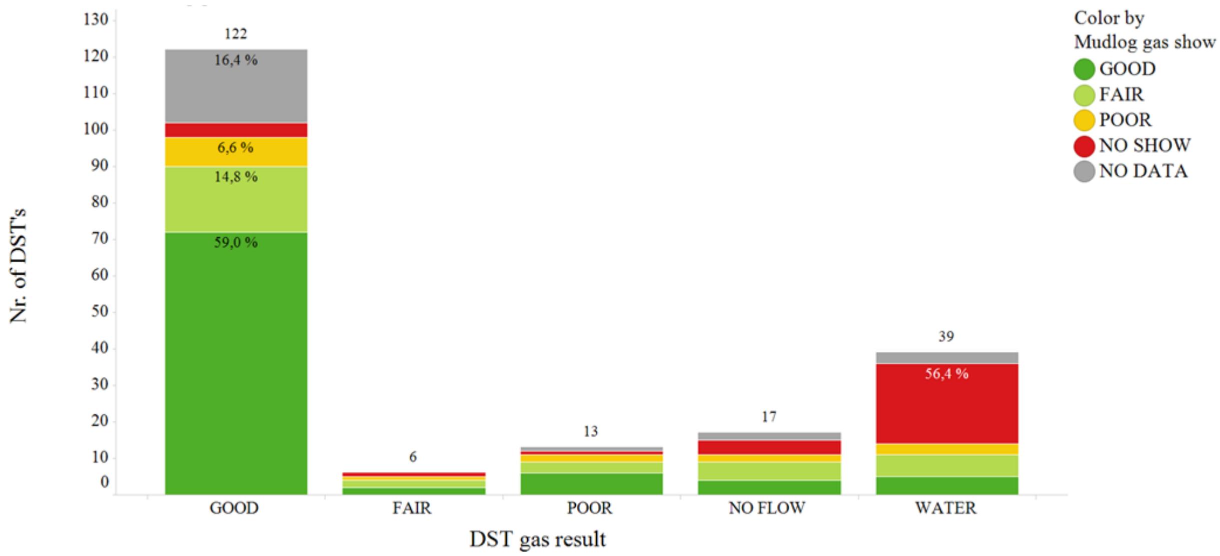

Figure 3.8: Correlation between gas DST's and log data for each DST target stratigraphy.

Figure 3.9 shows the number of DST's in which an oil flow was measured. The bars are colored according to the 'oil_show' rating from the 'Log data'. Most DST's that show a good oil occurrence correspond with either a good or oil show rating in the 'Log data'. In just one stratigraphy oil was only recognized in a DST and not in the mudlog.

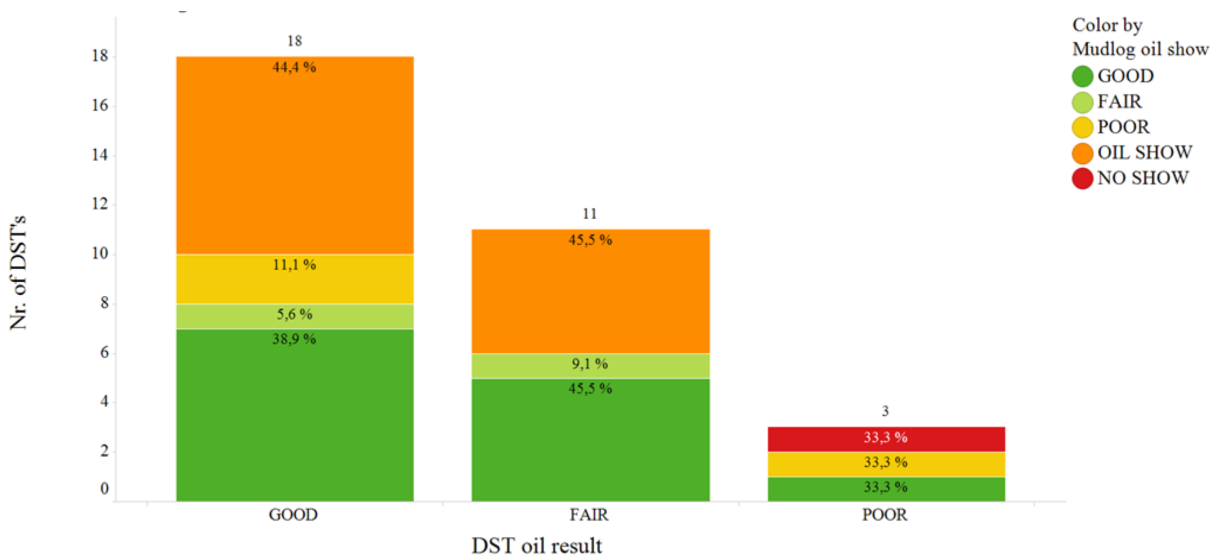

Figure 3.9: Correlation between oil DST's and log data for each DST target stratigraphy.

Figure 3.10 shows the number of RFT's which resulted in a non-oil result. The bar colors represent the best gas show found in the stratigraphic layer. Most of the RFT's from which a GAS major result was obtained correspond with a good log data classification. However, several of the RFT's that do not show any gas occurrences correspond with good and fair 'Log data' classifications.

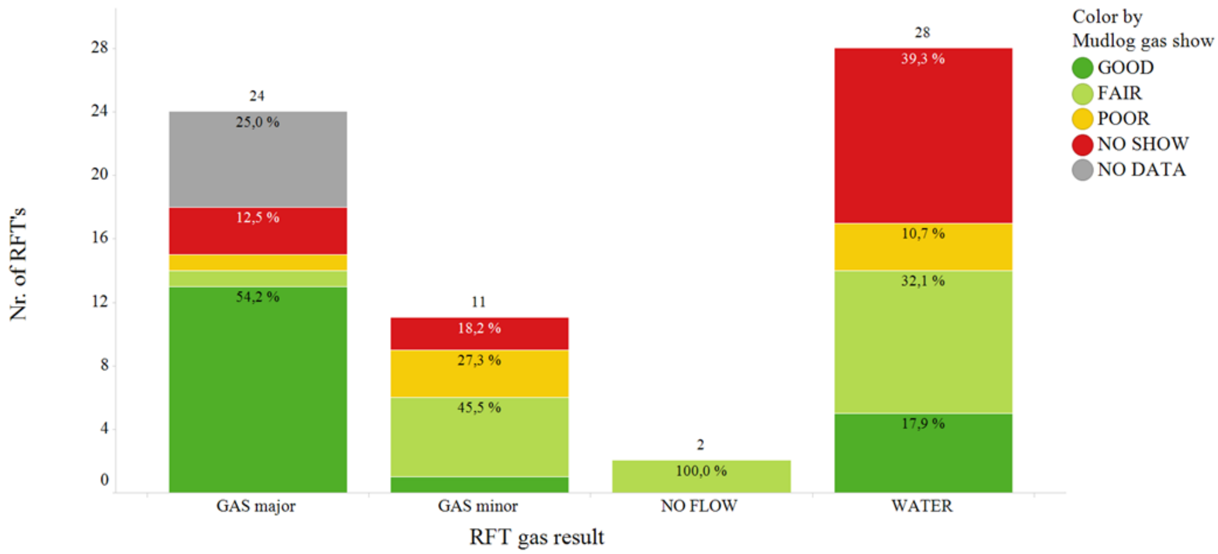

Figure 3.10: Correlation between gas RFT's and log data for each RFT stratigraphy.

Figure 3.11 shows the number of RFT's in which an oil flow was measured. The bar colors indicate the best oil show found in the same stratigraphic layer. Several RFT's in which an oil rich sample was obtained correspond with a no show 'Log data' rating. Also, most RFT's in which a minor amount of oil was found correspond to good oil shows in the 'Log data'.

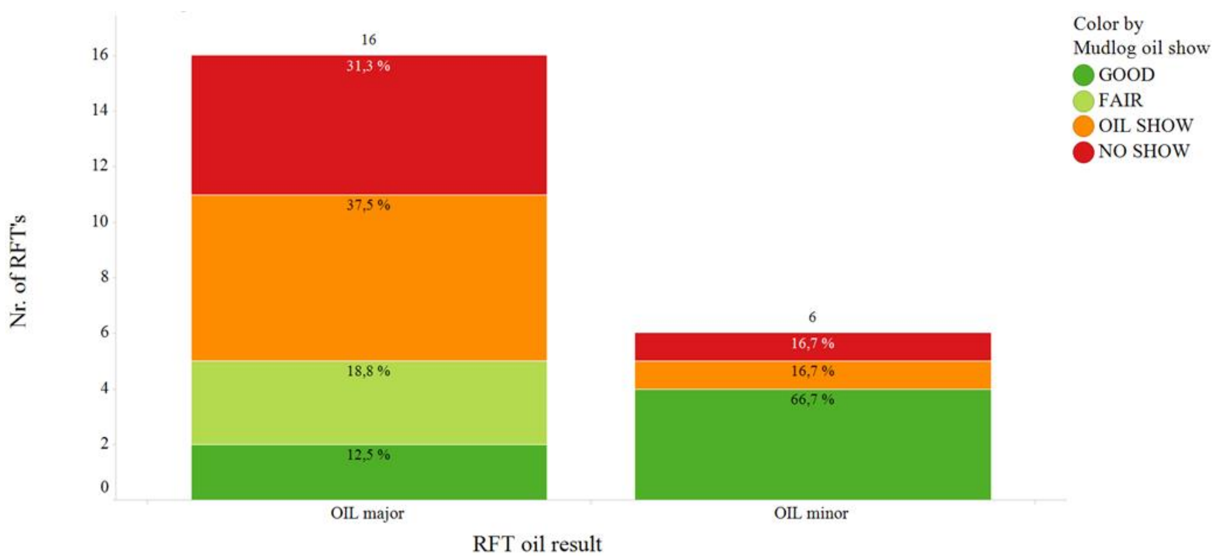

Figure 3.11: Correlation between oil RFT's and log data for each RFT stratigraphy.

4 Discussion & Recommendations

The main goal of this project was to extend the HC shows database. Also, the HC shows database has been used in several studies and their results have been described in the previous chapter. In this chapter the strengths and weaknesses of the database and the studies will be discussed. Subsequently, several recommendations for the extension of the database will be described.

4.1 Comparing interpreted gas shows to raw gas shows

By comparing interpreted gas shows to raw gas shows a few user input errors have been identified and corrected. Several gas shows that deviate from the classification scheme have been identified (e.g. HC shows in the NU, well flows and very high gas readings with lower PtBR ratios). This stresses the importance of user interpretations in classifying HC shows. Unfortunately, no missed gas shows have been identified in this study. All shows with a poor or no show 'interpreted_gas_show' rating and a good 'raw_gas_show' rating have been downgraded for good reason. Thus, the implementation of a 'raw_gas_show' column did not result in the anticipated result. Hence, there is no reason to maintain the 'raw_gas_show' in the HC shows database. Most of the errors found in this study are also identified by the 'user_input_check'.

4.2 Comparing the HC shows database to the Panterra MPA

41 out of 155 exploration wells that have been analyzed in the Panterra MPA are present in the HC shows database. In both datasets HC shows have been described in 266 stratigraphic groups. Because the datasets are based on different data sources they complement each other in identifying missed pay. 4 shows were given a good rating in both studies and their HC potential should be investigated. Several stratigraphic groups were given very different HC ratings in the two datasets. These discrepancies might indicate a missed show, misinterpretation or error in either one of the datasets and should be investigated more closely. My successor will investigate these interesting stratigraphic groups more closely.

Vis & Lutgert (2016) reviewed several wells from the Panterra MPA and concluded that some of the results are too optimistic. As explained before, the HC shows database is even more optimistic. This may be explained by the fact that the HC shows database has been designed to record all gas shows, this does not only include economically producible HC shows. E.g. the lower limit for a gas show to be producible is approximately a factor 10 larger than the 1000 ppm which is used as the lower limit for a good gas show in the HC shows database. Likewise, a DST flow rate of 50.000 m^3/d is not economically producible, however, it is given a good rating in the HC shows database.

4.3 Regional source rock study

The thickness of Zechstein salts was found to have very little to no effect on the locations of HC shows. However, the Zechstein salt is confirmed to be an impenetrable seal. Of greater importance is the location of the source rocks. Posidonia shales that have been deposited in grabens and basins are the source for HC shows in the overlying layers. On platforms and highs only thin layers of Triassic Jurassic sediments have been deposited or these stratigraphies have been eroded. If there are HC shows on platforms and highs they are located in sub-Zechstein stratigraphies. Westphalian coals are the most likely source rocks for these deep reservoirs.

The agreement between the source rock distribution described by Fattah, Verweij, Witmans, & ten Veen (2012) and the spatial distribution of the HC shows in the HC shows database confirm the methods and interpretations applied in this project.

4.4 The effect of mud type on gas readings

Different mud types show a large variation in their average total gas and average background gas values. OBM and WBM appear to cause much higher gas readings than PBM. However, the mud types that have been labeled as 'UKNOWN TYPE' and 'NOT SPECIFIED' have even lower gas readings. The 'NOT SPECIFIED' mud types mostly occur in older boreholes in which shallow reservoirs were targeted, such as the North Sea Supergroup or Jurassic sandstones. Shallower reservoirs typically result in lower gas readings.

Although there appears to be a relationship between the mud type and the magnitude of a gas readings this cannot been concluded from this study. First of all, the results are not unambiguous. Secondly, dividing the mud types into the three groups is prone to errors because occasionally mud types cannot be found on the internet. Also, industry drilling professionals have trouble to divide the mud types into groups ("Ik ben bang dat ik (en een hele oude mud engineer) je niet kunnen helpen" (Judith Weijman, Schlumberger)). Thirdly, gas readings are dependent on many parameters besides the mud type that is used during drilling. These parameters are not accounted for in this study.

4.5 Proofing the 'Excel deviatie tool'

The 'Excel deviatie tool' works properly. Only a few errors which are not caused by HC shows database errors or updated stratigraphies have been encountered. Errors that were caused by the 'Excel deviatie tool' have been communicated to Peter Bange.

Because some stratigraphic members in the HC show database differ from the latest stratigraphic definitions it might be interesting to investigate the possibility of updating the HC show database stratigraphy in the GISbase. At the moment the stratigraphy used in the excel spreadsheet is copied into the GISbase. The stratigraphy defined by TNO, is occasionally updated which results in a discrepancy between the HC show database stratigraphy and the TNO stratigraphy. However, consider that most of the stratigraphies updated by TNO are 'only' members. Also, no stratigraphic layers can be added to the database (i.e. no lines can be added to the database).

4.6 Spotfire QC and implementing an user input check

Analyses such as comparing 'interpreted_gas_show' ratings to 'raw_gas_shows' ratings, proofing the 'Excel deviatie tool' and a Spotfire QC resulted in a list of common user input errors. For this reason a 'user_input_check' which checks for 14 common errors was added to the HC shows datasheet. All error indicators have been individually analyzed and corrected if necessary. Now, the 'user_input_check' can be used by the analyst as an additional check on the data he/she entered.

4.7 Correlating mudlog data to DST and RFT results

Kickken, 2016 found a positive correlation between the phases (gas and oil) obtained from DST's and 'Log data'. In this study we extended this analysis by considering the ratings (GOOD, FAIR and POOR) given to DST results. Also, RFT sample results have been compared to 'Log data'. Note that the largest gas peak per stratigraphic interval is compared to a DST or RFT sample in the same stratigraphy. Consequently, the 'Log data' and 'Test data' results were not necessarily obtained at the same depth. Thus, a HC show should be regarded as an interval and not a point in depth.

A positive correlation was found between DST's and 'Log data' for both oil and gas shows. Therefore, the more detailed DST classification system that has been proposed in this study is adopted. Because DST's give an accurate indication of the producibility of a reservoir, more detailed classifications improve the functionality of the HC shows database. Also, production tests are only performed after careful evaluation of all the available data during and after drilling. Therefore, DST results that deviate significantly from 'Log data' results should be investigated closely because the discrepancy might be caused by user misinterpretations.

The 'Log data' correlates badly to both RFT samples in which HC's were encountered and RFT samples in which no HC's were found. This result was not unanticipated because RFT samples are foremost used to measure formation pressures. In addition, RFT samples contain only a small amount of fluid which is not representative for the reservoir fluid, e.g. drilling (mud) may have affected the lithology and fluids surrounding the borehole. Furthermore, the fill time of most RFT samples is unknown so several reservoir properties are not taken into account. Therefore, the HC show cannot be rated and only the dominant phase of a RFT sample can be determined depending on the fluid ratios of the sample.

4.8 Recommendations

In this section several recommendations on the design and functionality of the HC show database will be made to future analysts and EBN employees. The main goal of the HC show database project remains to
4.8.1 expand the database to the south.

Continuation of the HC shows database

It is important that the HC show database is continuously expanded for several reasons. First of all, the people involved in the project will stay up to date with the latest applications, improvements and goals of the project. Next, staying in contact with the former students who were responsible for the documentation and design of the project is easier when they have met in person. From personal experience I know that a
4.8.2 new analyst will have to ask many questions to his/her predecessor. These questions are easier and much less time consuming to answer in person than over a digital medium. Once the project has come to a hold it will be hard to start off for a new analyst.

Testing the HC show database

The Spotfire analysis showed that design flaws and errors in the HC shows database can be identified by using the database. Also, the HC show database is reaching an extent at which it becomes a meaningful tool for HC exploration. Therefore, the database should be tested thoroughly to improve its quality.

Sorting '(SW-)core' HC show classifications

The (sw-)core show classifications should be separated into gas and oil result columns (similar to 'Test data'). At the moment both oil and gas shows observed in (sw-)cores have the same classification names and cannot be distinguished between. Alternatively, the HC show classifications can be changed to a new classification system in which the classifications discriminate between gas and oil shows.

4.8.3 Update HC show symbols for QGIS

The HC show symbols designed by Kickken, 2016 do not cover all information. To visualize as much data as possible in a map, the HC show symbols have to be redesigned. This subject has been discussed with my successor and a new symbol has been proposed. At the moment custom HC show shapes can only be
4.8.4 imported to QGIS, but it is not unlikely that this feature will be implemented in Spotfire.

Removing undefined stratigraphies

Find HC shows in undefined (UNDEF) stratigraphic layers and change the 'STRAT_CODE' to the corresponding super group, group or formation stratigraphic code.

4.8.5

Reconsider document source linking

The idea behind source linking in the HC show database is to have quick access to the data on which HC
4.8.6 show classifications are based. However, over time a considerable number of links to Livelink data sources have become corrupted. In addition, linking to data stored on Livelink will not work for a public database. Therefore, a new source linking method which is independent of Livelink may be preferable.

4.8.7 Complementing missing data

It is important to keep track of missing data (most often mudlogs) in the HC show database. The nlog servicedesk has been contacted in an attempt to recover some missing data. Furthermore, most confidential data is available on Livelink. If not, contacting the operator can be considered.

4.8.8

Add a confidentiality label to the HC show database

A confidentiality label should be added to the HC show database before it is made public. A confidentiality label is already present in the 'gas composition database' and can be designed accordingly and implemented using the same method. A method to implement a confidentiality label can be by adding a column with the
4.8.9 required date from the 'meta-data database' and calculating which boreholes are younger than five years.

Investigate how to combine EBN databases

On the GISbase and nlog several databases are available to EBN employees. There is a huge potential in combining these databases. Some examples are described below.

- The HC shows database can be compared to **Well Meta Data** such as the well status (producing, dry, suspended, technical failure, gas shows, oil shows etc.). This comparison can serve as a quality control on the HC shows database and its interpretation criteria. E.g. producing boreholes typically have a HC gas value of 1% or higher which translates to 10000 ppm. In the HC shows database a GOOD gas show requires merely 1000 ppm if the other conditions are favorable.
- A comparison to **Well Meta Data** also allows us to define criteria for economically producible reservoirs. As discussed before, the HC show database is rather optimistic in classifying HC shows for the purpose of not missing any HC shows. If the criteria are available, economically viable gas and oil shows can be designated in a Spotfire analysis.
- The HC shows database can be compared to the **Gas Composition database**.

- The HC shows database can be compared to the **Geo Drilling Events (GDE) database**.
- By comparing the HC shows database to the **Stranded Fields** (gestrande velden) **database**, boreholes that have good HC potential and are not considered in the stranded fields database on nlog can be designated.

4.8.10 Default HC show database Spotfire project

Design a default Spotfire project for the HC show database which includes basic features such as a map chart showing gas and oil occurrences, a bar chart showing the HC shows per stratigraphy, text descriptions and explanations etc. Put this Spotfire project in the 'Library' folder on the GISbase where it will be maintained by the HC shows database analyst. Other EBN employees can find it here and save it locally where they can make changes to the project.

4.8.11 Block diagram workflow

Consider redesigning the workflow to a block diagram in which the right approach to classifying HC shows is guaranteed.

4.8.12 Enter data directly into the GISbase

HC shows data can be entered directly into the GISbase if the analyst is given access to the database by Peter Bange. This has several advantages. First of all, the GISbase does not have to be updated manually so the exploration team will have access to the latest HC show data. Also, some exploration team members can be given access to the HC shows database so they can correct mistakes and improve show classifications. Furthermore, users can sort columns and rows in MS Access without changing over data. This reduces the risk of the HC show database becoming corrupted by column and row sorting. At long last, several databases can be combined in MS Access. To combine databases a good practice has to be developed and applied to all databases to make sure that they are compatible.

4.8.13 Incorrect TNO defined stratigraphy for lower Zechstein

The lower Zechstein TNO stratigraphy for several boreholes does not correspond to the stratigraphy recognized on the composite logs and mudlogs (see section 2.5.2). In the HC shows database, the TNO stratigraphy is used although HC shows are recognized to fall in unlikely lithologies and stratigraphies. E.g. shows that are expected to be located in the Zechstein carbonates are now located in anhydrite layers. Therefore, analyses at member level are not reliable. To improve the database quality, the Zechstein TNO stratigraphy should be updated or the analyst should diverge from the Zechstein TNO stratigraphy.

5 Conclusions

The primary goal of this project was to expand the HC shows database. While complementing the database, several expansions, improvements and questions presented themselves. A selection of topics has been resolved and elaborately described. The remaining expansions and improvements have been described in 4.8 Recommendations.

- The HC shows database has been expanded from 448 to 528 boreholes, mainly in the L-quadrant.
- The HC show classifications have been refined. Now self-explanatory and uniform classifications are used for 'Log data', 'Test data' and '(SW-)core Data'.

- The HC show classifications for DST's and RFT samples have been updated. Indistinct HC classifications have been refined to provide more information on the quantity of HC's.
- Columns with the stratigraphic group code, TVD and well trajectory/deviation data have been added to the HC shows database.
- The HC shows database has been subjected to an extensive error checking through actively searching for inconsistencies and performing analyses. Consequently, an error check has been implemented in the database which checks for common user input errors.
- A HC show classification system that is only dependent on peak and background gas values ('raw_gas_show') has been tested. All the HC shows with high gas readings and a poor 'interpreted_gas_show' classification have been 'downgraded' for good reason. Therefore, the 'raw_gas_show' column has been removed from the HC shows database.
- The potential of combining databases has been identified by comparing the HC shows database to the Panterra MPA. Several recommendations and ideas have been described. The new HC shows database analyst will investigate the opportunities more extensively.
- A regional source study has been performed. From this study we can conclude that the HC shows database is in accordance with the depositional environments of HC source rocks in the Netherlands.
- Spotfire has proven to be a powerful tool for analyzing the HC shows database. Especially the map chart allows for extensive regional analyses.
- The 'Excel deviatie tool' has been tested extensively and several errors have been communicated to its administrator. Comparing the stratigraphies in the 'deviatie tool' and HC shows database designated the stratigraphies in the database that are out of date because they have recently been updated recently by TNO.
- A QC has been performed on the database by correlating DST results to mudlog data. The positive correlation indicates a high database quality.
- The project has been handed over successfully to Jan Westerweel. To his aid the workflow for the HC shows database has been reviewed and updated with the latest improvements. Additionally, two chapters were added to the HC shows example ATLAS that future analysts can refer to.

6 Acknowledgements

First of all, I would like to express my gratitude to EBN for offering this challenging and very informative internship opportunity. At EBN I experienced a friendly and professional setting in which employees were always prepared to offer a helping hand. I would like to thank Guido Hoetz for supervising me at EBN. His support and the constructive dialogs are very much appreciated. I would also like to thank Marten ter Borgh and Annelieke Vis for their help on specific topics. I would also like to thank Peter Bange for his explanations of the GISbase and for regularly updating the HC shows database onto the GISbase. I would also like to thank dr. Fred Beekman from the Utrecht University for his guidance and help in shaping a roadmap for my internship. I would also like to thank the previous students who worked on the HC shows database, Chris Heerema, Youri Kickken and Claudia Haindl, for their great work. A special thanks to Youri Kickken for his patience and explanations while introducing me into the topic. At last, I would like to thank Jan Westerweel for continuing the project and I wish him the best of luck!

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8 Appendix

Appendix A HC shows database Workflow_v3

Red colored text indicates the changes made to the Workflow in this project.

Data analysis workflow – Version 3.0

1. General remarks

- If abbreviations are used in a description, translate them to full words. Abbreviations are often explained at the top of the log.
- Use quotation marks to quote a remark from the document.
- Keep the datasheets in alphabetical order (as on Nlog), when adding new borehole entries.
- Read the document 'Database lay-out, examples, and pitfalls', and references therein, to become familiar with the database set-up.

2. Log data

Step 1.

Open excel file 'HC Show Datasheets' , tab 'Log data'

Step 2.

Check whether for the selected borehole TNO stratigraphy is available in the excel file. If the borehole has already been entered in the excel file, analyze the (mud-)log per TNO defined stratigraphic layer.

- If the borehole has not been entered in the excel file, add new rows and note down the (TNO) borehole code in the column 'borehole', the top of the stratigraphic layer in the column 'STRAT_TOPLAAG_AH', the bottom of the stratigraphic layer in the column 'STRAT_BASISLAAG_AH' and the stratigraphic code in the column 'STRAT_CODE'. The stratigraphic sequence for most boreholes can be found at 'Digitale werkplek' -> 'Basisregistraties' -> 'Boringen' -> Zoeken borehole -> double click the borehole -> '7. Stratigrafie'. Here, click 'Naar CSV exporteren' and copy the required columns into the HC shows datasheet. Otherwise, the stratigraphy name and top and bottom depths may be found on nlog, (Step 3). In this case, add the corresponding stratigraphic codes by hand.
- If no stratigraphy is available for the borehole, enter the borehole code in the column 'borehole' and 'NO DATA no stratigraphy available' in columns 'data_source_gas', 'gas_show', and 'oil_show'. Select a new borehole for analysis or check with your supervisor.
- Alternatively choose to enter the stratigraphic intervals by hand if advised by your supervisor.

Step 3.

Go to www.nlog.nl, click 'boringen', click 'keuzelijst' and select the borehole you are analyzing.

- If your selected borehole is not available in the list, note down 'NO DATA' for the entire borehole, in the columns 'data_source_gas', 'gas_show' and 'oil_show'.
- If the selected borehole has one or more sidetracks (ST's) due to technical failure (which will be indicated in the 'administratieve gegevens'), analyze the borehole with the deepest stratigraphy (usually the last sidetrack). The entire columns 'gas_show', 'oil_show' and 'data_source' of the other sidetracks and original borehole are annotated with 'NO DATA sidetracked'. If several sidetracks were completed successfully, check whether good hydrocarbon shows are present in any of the other boreholes. If this is the case, analyze this borehole too.

Step 4.

Check whether a document with a gaslog is available for your selected borehole. These documents can be named 'Composite Well log', but more often gaslogs can be found under the heading 'Documenten', named e.g. 'Litholog', 'Geological log', 'Exlog', 'Mudlog' etc. Check column 'data_source' for the various document names of previously analyzed wells.

- Any general comments about the entire selected log, can be mentioned in the column 'general_borehole_comments', preferably in the first row of the selected borehole. It's better to note down too much instead of too little information.
- If the selected borehole has no log data because the borehole is confidential/recently drilled (there will be no data files at all on nlog), enter 'NO DATA confidential' in columns 'gas_show', 'oil_show', and 'data_source'. If there are data files but the gaslog has not been put online annotate the entire columns with 'NO DATA entire gaslog useless/absent' and talk to your supervisor about contacting the nlog administration. In both cases you can try to find the data on livelink (Enterprise -> Technology -> Datamanagement -> POC Putten).

Step 5.

Check whether the depth is 'measured along hole below rotary table' (MAHBRT), instead of 'rotary table', also 'kelly bushing' (KB) is often referred to. A good method to verify this, is to correlate some formation depths or terminal depth (TD) with the TNO stratigraphy.

- If not measured from the 'rotary table' or 'kelly bushing', correct for it or select another log.
- If displayed only as true vertical depth (TVD), select another document with along hole (AH) annotation or ask supervisor
- If your selected log is measured in feet, use the conversion factor (meter = feet*3.2808) to translate the depth into meters. For the convenience you can temporarily copy and converse the imported formation depths into feet, in a separate tab, to better match it with the log.

2.1 Gas shows per formation

Step 6.

Check whether the gas log data is based on continuous measurements or on (ir)regular measurements for the selected stratigraphic interval.

- If completely missing or if the gas readings are unreliable because the gas measurement equipment broke down, note down 'NO DATA part gaslog useless/absent' for the selected formation, in the column 'gas_show' and proceed Step 14.
- If partially missing, mention it in the 'comments_gas' column

Step 7.

Read off, from the chromatograph section on the log, the highest methane (C1) gas reading for the selected stratigraphic interval and note it down in column 'c1_max'. Additionally, note down the exact depth of this measurement in column 'exact_measurement_depth_gas'. Furthermore, note down the other measured alkanes (C2-nC5) in column 'c2_max' to 'nc5_max', measured at the same depth as C1. The sum of all alkane columns is noted in column 'accumulated_gas'. Lastly, note down the measurement unit (ppm or %) in column 'gas_unit'.

- If an alkane concentration is measured at 0 or is below the measurement threshold, the entered value is '0'.
- If an alkane is not measured, note down 'NOT MEASURED' in respective alkane column ('c1_max' to 'nc5_max').
- If the gas reading is illegible, note down 'NO DATA part gaslog useless/absent' in the respective alkane column ('c1_max' to 'nc5_max').
- If all gas readings are '0' or below the detection limit, enter 'NO SHOW' in the column 'interpreted_gas_show' and select the next stratigraphic interval.
- If the gas readings are non-zero but constant, such that you cannot identify any maxima, enter 'NO SHOW' in the column 'interpreted_gas_show', note down the background gas level and enter 0 in the columns for accumulated gas and for all the measured alkanes.
- If no chromatograph analysis is available, use the total gas graph and enter its value directly into the 'accumulated_gas' column and note down 'NOT MEASURED' in the columns 'c1_max' to 'nc5_max'.
- If no total gas graph is available but point measurements annotated with numbers instead, note the 'highest' spot measurement within this formation. In this case also check the well report for additional information.
- If a gas peak is exactly at the boundary between two stratigraphic units it will count towards the unit below.

Example:

ROSLU	2500-2700m
ROSLL	2700-2840m

Show at 2700m is considered part of ROSLL

To be more accurate, one can consult gamma ray and resistivity measurements (often composite log) to exactly determine the depth of a lithological variation, oil/water or gas/water contact (see ATLAS chapter 7).

- Ignore peaks that coincide with coal beds. In a stratigraphic unit with many coal shows find and enter the largest peak that does not coincide with coal. It's important that you mention the coal shows in the comments.
- Ignore peaks that are annotated as connection gas (sometimes CG) or trip gas (sometimes TG or TRG) – check the header of the log for the used abbreviations but **be aware** the loggers often don't stick to the suggested format. These gas shows are usually very narrow, strong spikes that don't necessarily coincide with lithological changes. If you are unsure ask your supervisor and note it in the 'comments' column.

Step 8.

Estimate the background gas concentration associated with the highest gas reading and note it down in column 'background_gas'. The background gas is, more or less, the average value of a stratigraphic layer or a thick rock layer when ignoring the peaks and minima.

Step 9.

Mention of any other gases (incl. non-HC e.g. N_2, H_2, CO_2, H_2S) in the selected stratigraphic interval is noted down in the column 'other_gases'

Step 10.

Determine the dominant lithology at the same depth as the highest gas reading and note it down in column 'lithology_gas'. If available, use the interpreted lithology column on the log, else use the cuttings description column or find lithology at same depth on other log. Any other relevant lithology related info can be described in the 'comments_gas' column.

Step 11.

Based on the highest gas reading, background gas and lithology the gas show needs to be classified. The classification scheme consists of 'NO SHOW', 'POOR', 'FAIR' and 'GOOD', one of which has to be entered in the column 'interpreted_gas_show'. Below some rules of thumb for the classification are given but in the end you may have to rely on your geological background and adjust depending on the specific situation. These rules are for "classic" cases of gas shows. Before you start your evaluation do consult the ATLAS of show-examples which also contains less obvious situations, so you get a feeling of how to judge gas shows in different geological contexts.

(PtBR = Peak-to-Background Ratio)
("Peak" = absolute difference between the maximum accumulated gas and the background)
Rules of thumb as a step-by-step guide:

- Peak < 500ppm (0,05%), or peak in halite → NO SHOW

  For larger peaks:

  - PtBR < 2 → NO SHOW

- PtBR < 3 → POOR

  For ratios > 3:

  - Mudstone/shale/claystone/marl → POOR
  - Siltstone → FAIR

    For sandstone/limestone/chalk:

    - PtBR < 5 and/or peak < 1000ppm (0,1%) → FAIR
    - Otherwise → GOOD

Rules of thumb as a table:

Interpreted gas show classification					
		NO SHOW	POOR	FAIR	GOOD
Interpreted	Peak gas	< 500ppm (0,05%)	> 500ppm (0,05%)	> 500ppm (0,05%)	> 1000ppm (0,1%)
	PtBR	< 2	2 < PtBR < 3	> 3	> 5
	Lithology & composition/grading & thickness	halite	mudstone/shale/ claystone/marl	siltstone	sandstone/ limestone/chalk

Note when using the table: Out of the 3 criteria (peak gas, lithology and PtBR) the one which results in the worst classification determines the final classification given to the show. Further, as an example, if a show just makes it into the 'FAIR' category based on peak and PtBR and it is in siltstone, this further lowers the show quality, so it may be placed in the 'POOR' category.

Peaks in halite (or rock salt) are classified as "NO SHOW" because halite has zero porosity and permeability. Due to drilling complications in this lithology you may often encounter peaks in gas readings, but these are artefacts which stem from stuck pipes, pulling out and so on.

It is important to note that these rules are not set in stone. If for example the background reading in a sandstone is already in the 10000s of ppm, than a peak of 3 times the background reading can already be considered a GOOD show, even though according to the above scheme it would be at the POOR/FAIR boundary. Also, in situations where different lithologies are interbedded, where a show coincides with a thin bed, or when there is grading from one lithology to another, a middle ground between the classifications has to be chosen. Another common case is that limestone and sandstone can have high silt or mud contents tendentially lowering the quality of the show, so if the PtBR is at the boundary between two classifications you might choose the lower one. Comments about this should be put into the column 'additional_description_gas'.

A noteable exception from these rules that you need to be aware of, is the shallow North Sea formation which has generally high porosity, even if the lithology is clay – so strong shows in clay within this formation should be classified as GOOD.

There is a large subjective component in making the classification – if you are not sure what to do, ask your supervisor.

Step 12.

Read off the mud type. Do this by looking up the first mention of mud data you encounter above (shallower than) the depth measurement of the highest gas reading. We assume here that, if any significant alteration is made to the mud type, this is stated on the log. Also, at the top of many composite logs the depth intervals at which specific measurement tools have been used are indicated. The mud types that were used over these intervals are also described and can be used in the database.

- For mud type, distinguish between water based mud (WBM), oil based mud (OBM) or polymer based mud (PBM), enter this in column 'mud_type'.
- If the mud type is not specified, note down 'NOT SPECIFIED' in column 'mud_type'.

Step 13.

Read off the mud weight by looking up the first mention of mud weight you encounter above (shallower than) the depth measurement of the highest gas reading and enter this in column 'mud_weight'.

- Mud weight is either measured in pounds per gallon (ppg) or sg (10^3 kg/m^3), note this down in column 'mw_unit'.
- If the mud weight is not specified note down 'NOT SPECIFIED' in column 'mud_weight'.
- Any other relevant info regarding mud, can be noted down in 'comments_gas'.

2.2 Oil shows per formation

Step 14.

Check whether oil show related data is missing (e.g. part of the selected log is missing) in the selected stratigraphic interval. Be aware that many wells have no oil shows, so if there is no mention of oil that does not necessarily mean that the data is missing.

- If completely missing, note down 'NO DATA part gaslog useless/absent' for the selected formation, in the column 'oil_show'. Select the next stratigraphic interval.
- If partially missing, make a mention of it in the 'comments_oil' column.

Step 15.

If available, read off the 'best' oil classification from the selected log for each stratigraphic unit and note it down in column 'oil_show'. Additionally, note down the exact depth in column 'exact_measurement_depth_oil'. Always carefully check the comments and description section for any oil show mentions.

- Adjust the show classification so that it fits the 'POOR', 'FAIR' and 'GOOD' subdivision.
- If no classification of the oil show is given, note down 'OIL SHOW' in column 'oil_show'.
- If no oil show is present or the oil show is in halite, note down 'NO SHOW' in column 'oil_show'.

Step 16.

Note down the description (fluorescence, cut, staining etc.) of the oil show in column ‘oil_show_description’. If abbreviations are used, translate them to full words. Any other relevant remarks to the show are noted down in column ‘additional_description_oil’.

Step 17.

Read off the lithology at the same depth as the ‘best’ oil show and note it down in column ‘lithology_oil’ (max. two words, preferably one). If available, use the interpreted lithology column on the log, else use the cuttings description column. Any other relevant lithology related info can be described in the ‘comments_oil’ column.

2.3 Documentation

Step 18.

Save the used document in Livelink, name it as displayed on nlog and add the borehole name in front of it.

Step 19.

Paste the name in column ‘data_source’ and paste the Livelink-link in column ‘data_source_link’.

Step 20.

Give the used data source a quality label (POOR, FAIR, GOOD), note down in column ‘data_quality’.

Step 21.

Enter the interpretation date in column ‘create_date’, your 3-letter user ID in column ‘create_user_id’ and enter ‘EBN’ in column ‘show_interpreter’.

Step 22:

Make sure the ‘user_input_check’ is ‘GOOD’. Otherwise find the source of the error and correct if possible. Make a note in the ‘comments_gas’ or ‘comments_oil’ stating the reason for the ‘error’.

Step 23.

Select the next stratigraphic interval (Step 6) or next data type.

3 (Sidewall-)Core data workflow

Step 1.

Open excel file 'HC Show Datasheets' , tab '(SW-)core data'.

Step 2.

Insert the name of the borehole you want to analyze in column 'borehole'.

Step 3.

Go to www.nlog.nl, click 'boringen', click 'keuzelijst' and select your desired borehole.

- If your selected borehole is not available, note down 'NO DATA' for the borehole entry, in the columns 'show_classification' and 'data_source' and select a new borehole or data type.
- If the selected borehole has one or more sidetracks (ST's) be sure to check for core data in all the sidetrack files since they are often mixed up, and double-check in the header of the file which sidetrack the core is from. If no (sw-)core has been taken and a borehole has been sidetracked, enter 'NO DATA no (sw-)core, sidetracked' in the columns 'show_classification' and 'data_source'.
- If no (SW-)core data of the selected borehole is available because the borehole is confidential/recently drilled (i.e. you can't find any files on nlog), enter 'NO DATA confidential' in the columns 'show_classification' and 'data_source'.

Step 4.

Check the documents for any core or sidewall-core analyses. This data can often be found in e.g. '(Sidewall-)core report', 'Core analysis', 'Composite log', 'End of well report' etc.

- If no core or sidewall-core data is found note down 'NO DATA no (sw-)core' for the borehole entry, in the columns 'show_classification' and 'data_source' and select a new borehole or data type.
- (SW-)core data is often mentioned on the same document from which log data is retrieved.
- If an (SW-)core is mentioned in other files but no descriptions have been put online, also enter 'NO DATA' but add in the 'comments' column that the data file is missing.

Step 5.

Not all (sidewall)core data is focused on HC show description. Often, (sw-)core samples are only analyzed for petrophysical characteristics (e.g. permeability, porosity), whereas HC indications are not described. In this case interpret as 'NO DATA'. Additionally, be alert for any negative indications regarding whether any cores or (sw-) cores were sampled, this can save you some time.

Step 6.

Group the cored intervals or sidewall cores together based on stratigraphic interval and show/lithological description. To get an idea of the stratigraphic intervals, check the tab 'Log data' and look for the selected borehole. The determined intervals are entered in columns 'top_depth' and 'bottom_depth', each new interval receives a separate row.

- The depth of a single sidewall core samples is entered in column 'exact_measurement_depth'.

Step 7.

Enter 'CORE' or 'SWC' in column 'show_source' for each created interval or sample.

Step 8.

Detailed description of the hydrocarbon show (for each interval) is entered in column 'oil_gas_show_description'.

- (Large) intervals, which do not contain any hydrocarbon shows get classified as 'NO SHOW', entered in column 'show_classification' and 'data_source'.

Step 9.

The lithology is averaged for the chosen interval and entered in column 'lithology' (2 words max.). Any important structural or lithological features, related to the HC show can be added in column 'oil_gas_show_description'.

Step 10.

Based on the HC show description, continuity of the show, and lithology of the determined interval, classify the show as 'POOR', 'FAIR' or 'GOOD'. This is entered in column 'show_classification'.

Step 11.

Based on overall quality and completeness of the data description, classify the data quality as 'POOR', 'FAIR' or 'GOOD' in column 'data_quality'.

Step 12.

Any additional remarks (e.g. about the lithology, sampling interval, quality) can be noted down in the 'comments' column.

Step 13.

Save the used document in Livelink, name it as displayed on nlog and add the borehole name in front of it.

Step 14.

Paste the name in column ‘data_source’ and paste the Livelink-link in column ‘data_source_link’.

Step 15.

Enter the interpretation date in column ‘create_date’, your 3-letter user ID in column ‘create_user_id’ and enter EBN in column ‘show_interpreter’.

4 Test data workflow

Step 1.

Open the Excel file ‘HC Show Datasheets’ , tab ‘Test data’.

Step 2.

Insert the name of the borehole you want to analyze in column ‘borehole’.

Step 3.

Go to www.nlog.nl, click ‘boringen’, click ‘keuzelijst’ and select your desired borehole.

- If your selected borehole is not available, note down ‘NO DATA’ for the entire borehole, in the columns ‘HC_result’ and ‘data_source’ and select a new borehole or data type.
- If no test data of the selected borehole is available because the borehole is confidential/recently drilled, enter ‘NO DATA confidential’ in columns ‘HC_result’ and ‘data_source’.

Step 4.

Check the documents for any DST and/or RFT data. Only RFT samples are recorded in the data sheet. You can ignore measurements where no samples were taken. Test data can often be found in e.g. ‘production test data’, ‘End of well report’, ‘Composite log’, ‘Technische gegevens’ etc.

- If no test data is found note down ‘NO DATA no test’ for the borehole entry, in the columns ‘HC_result’ and ‘data_source’.
- If no test data is found and a borehole has been sidetracked note down ‘NO DATA no test, sidetracked’ for the borehole entry, in the columns ‘HC_result ’ and ‘data_source’.

- DST and RFT data is often mentioned on the same document from which log data is retrieved. Also, be alert for any negative indications regarding whether any DST's or RFT's were carried out, this can save you some time.

4.1 DST

Step 5.

Enter 'DST' in column 'test_type'.

Step 6.

Enter the top and bottom of the tested interval in columns 'top_depth' and 'bottom_depth', if more intervals are tested for **this** one DST, enter up to 4 intervals ('top_depth1' to 'bottom_depth4').

- If a single test comprises more than four intervals, the intervals are lumped together. The top of the cumulated intervals is entered in column 'lumped_top_depth' and the bottom in column 'lumped_bottom_depth'.

Step 7.

- Per given DST, select the flow period with the highest flow rate and note the magnitude of the flow rate in column 'max_flowrate' and the flow rate unit in column 'flowrate_unit'. If no flow rate is available, enter 'NO DATA' in the columns 'HC_result' and 'data_source'.

Step 8.

Note down the result ('NO DATA', 'WATER', 'NO FLOW', 'GOOD', 'FAIR', 'POOR') of the DST in the column 'HC_result'.

- If you are unsure about the data, mark the cells and ask your supervisor.
- If a DST has been taken but its flow rate and/or outcome are missing/unreadable, enter 'NO DATA'.
- If the result of a DST is mud, brine or water, enter 'WATER'.
- If the result of a DST is tight or no flow, enter 'NO FLOW'.
- If there is a **gas** flow, find the maximum net **gas** flow rate for this DST. Note down the result of the net **gas** flow in the column 'HC_result' according to table DST gas. Make sure the net **gas** flow rate is in m^3/d.

Table: DST gas				
	Net flow rate (m^3/d) > 50.000	10.000 < Net flow rate (m^3/d) < 50.000	1 < Net flow rate (m^3/d) < 10.000	Net flow rate (m^3/d) < 1
Result	GOOD	FAIR	POOR	NO FLOW

- If there is an **oil** flow, find the maximum **oil** flow rate for this DST. Note down the result of the **oil** flow in the column ‘HC_result’ according to table DST oil. The watercut is the amount of water in the oil-water mixture. Because DSTs only use small amounts of fluids, only oil will reach the surface in most cases. If this is the case, the result of the DST depends solely on the oil flow rate. If not, the results depends on the watercut and the oil flow rate according to table DST oil. If the net oil flow rate > 10 m3/d, this is a GOOD show. If, 1 m3/d < net oil flow rate < 10 m3/d, this is a FAIR show. If the net oil flow rate < 1 m3/d, this is a POOR show. Make sure the **oil** flow rate is in m^3/d. The table below may help in the classification process but is not conclusive because a borehole with watercut of 70% and a flow rate of 90 m^3/d is still a GOOD show.

Table: DST oil				
	Flow rate (m^3/d) > 100	10 < Flow rate (m^3/d) < 100	0,1 < Flow rate (m^3/d) < 10	Flow rate (m^3/d) < 0,1
Watercut < 90%	GOOD	FAIR	POOR	NO FLOW
90% < Watercut < 99%	FAIR	FAIR	POOR	NO FLOW
Watercut > 99%	POOR	POOR	POOR	NO FLOW

- If there is water present next to the oil, note down the oil cut and the watercut in the comments.

Step 9.

Also note down the HC_result obtained in Step 7 in one of the columns ‘gas_show_result’ or ‘oil_show_result’.

Step 10.

Enter the maximum flow rate in m^3 in the column ‘max_flowrate_(m^3/d)’. If necessary use the ‘Calculations’ tab to convert the flow rate to m^3/d.

Step 11.

Any other relevant data can be entered in column ‘comments’.

Step 12.

If applicable, repeat these steps for all DST's related to this borehole.

4.2 RFT

Step 13.

Only **RFT samples** are recorded in the data sheet. You can ignore measurements where no samples were taken. If a sample has been taken successfully, enter 'RFT' in column 'test_type'.

Step 14.

Enter the RFT testing depth (mAHBRT) in the column 'exact_measurement_depth'.

Step 15.

Note down the result ('NO FLOW', 'WATER', 'GAS major', 'OIL major', 'GAS minor', 'OIL minor', 'NO DATA') of the RFT in the column 'HC_result'.

- If you are unsure about the data, mark the cells and ask your supervisor.
- Failed tests are ignored.
- If a test has been done but the data is not available or unreadable, enter 'NO DATA'.
- If the formation is tight or there is no flow into the chamber, enter 'NO FLOW'.
- If the chamber is filled with only water, brine or mud, enter 'WATER'.
- From the chamber with the best HC show note down the dominant fluid in the column 'HC_result'. A cutoff of 10% under downhole conditions is used to determine if HCs are the dominant phase. If there is no mention whether the measurements were taken under surface or downhole conditions, assume they were taken under downhole conditions. If explicitly mentioned that the measurements were taken at surface conditions, than recalculate the gas volume to downhole conditions using the compressional gas factor of 100/km (water and oil are assumed to be incompressible).
  This results in the following rules of thumb that can be used to determine the dominant fluid:
    - *If oil cut > 10% and water/brine/mud cut <90% than oil is dominant (1 l oil is dominant over 10 l water) (='OIL major')*
    - *If oil cut <10% (or trace oil) and water cut/brine/mud >90% than water is dominant (='OIL minor')*
    - *1 l oil is dominant over 1000 l gas (='OIL major')*
    - *If gas cut > 90% and water/brine/mud cut <10% than gas is dominant (1 l gas is dominant over 0,1 l water) (='GAS major')*
    - *If gas cut <90% and water cut/brine/mud >10% than water is dominant (='GAS minor')*
    - *If the ratio between phases is not known/provided, enter either 'GAS major' or 'OIL major'. Explain in the 'Comments' that the ratio is not known and therefore the classification is not based on the data_source but on the purpose of the database to not miss any good HC shows.*
- Note down the amount of each fluid that is present in the comments.

Step 16.

Also note down the HC_result obtained in Step 14 in one of the columns 'gas_show_result' or 'oil_show_result'.

Step 17.

If a chromatographic analysis was performed, note down the results in columns ‘c1_max’ to ‘nc5_max’.

Step 18.

Any additional remarks (e.g. about the lithology, sampling interval, quality) can be noted down in the ‘comments’ column.

Step 19.

Based on overall quality and completeness of the data description, classify the data quality as ‘POOR’, ‘FAIR’ or ‘GOOD’ in column ‘data_quality’.

Step 20.

Save the used document in Livelink, name it as displayed on nlog and add the borehole name in front of it.

Step 21.

Paste the name in column ‘data_source’ and paste the LiveLink-link in column ‘data_source_link’.

Step 22.

Enter the interpretation date in column ‘create_date’, your 3-letter user ID in column ‘create_user_id’ and enter EBN in column ‘show_interpreter’.

Appendix B

Appendix B.1

Excel 'raw_gas_show' Excel formula

```
=   IF(K2="Not yet investigated";K2;IF(LEFT($K2;5)="NO DA";K2;
    IF(AND(M2=0;OR(AND(W2="ppm";L2<500);AND(W2="%";L2<0,05))); "NO SHOW";
    IF(AND(M2=0;OR(AND(W2="ppm";L2>=1000);AND(W2="%";L2>=0,1))); "GOOD";
    IF(AND(M2=0;OR(AND(W2="ppm";L2>=500);AND(W2="%";L2>=0,05))); "FAIR";
    IF(OR(L2=0;AND(W2="ppm";OR(L2<500;L2/M2<2));(AND(W2="%";OR(L2<0,05;L2/M2<2)
    ))); "NO SHOW";
    IF(OR(AND(W2="ppm";L2>=500;L2/M2>=2;L2/M2<3);AND(W2="%";L2>=0,05;L2/M2>=2;
    L2/M2<3)); "POOR";
    IF(OR(AND(W2="ppm";L2>=1000;L2/M2>=5);AND(W2="%";L2>=0,1;L2/M2>=5));
    "GOOD";
    IF(OR(AND(W2="ppm";L2>=500;L2/M2>=3);AND(W2="%";L2>=0,05;L2/M2>=3)); "FAIR";
    "FALSE" )))))))))
```

where

K2 = 'interpreted_gas_show'

L2 = 'total_HC_gas '

M2 = 'background_gas'

W2 = 'gas_unit'

Appendix B.2

'AH_depth_gas' Excel formula

```
=   IF($I2<>"";$I2; IF($K2="Not yet investigated";"";
    IF(AND($B2<>"";$C2<>"";OR(LEFT($K2;5)="NO DA";$K2="NO SHOW"));($B2+$C2)/2;
    0,01)))
```

where

B2 = 'STRAT_TOPLAAG_AH'

C2 = 'STRAT_BASISLAAG_AH'

I2 = 'exact_measurement_depth_gas'

K2 = 'interpreted_gas_show'

Appendix B.3

'user_input_check' Excel formula

```
=	IF(G2<>"EBN";"";
	IF(OR(AND(I2<>"";NOT(ISNUMBER(I2)));AND(L2<>"";NOT(ISNUMBER(L2)));AND(M2<>"";NOT(ISNUMBER(M2))));"FALSE14";
	IF(AND(I2<>"";OR(I2<B2;I2>C2));"FALSE1";
	IF(AND(AC2<>"";OR(AC2<B2;AC2>C2));"FALSE2";
	IF(AND(I2="";OR(K2="GOOD";K2="FAIR";K2="POOR"));"FALSE3";
	IF(AND(AC2="";OR(AE2="GOOD";AE2="FAIR";AE2="POOR";AE2="OIL SHOW"));"FALSE4";
	IF(AND(I2<>"";OR(LEFT(K2;5)="NO DA";K2="Not yet investigated"));"FALSE5";
	IF(AND(AC2<>"";OR(LEFT(AE2;5)="NO DA";AE2="Not yet investigated"));"FALSE6";
	IF(AND(L2>0;M2>L2);"FALSE7";
	IF(AND(W2="%";OR(L2>100;M2>100));"FALSE8";
	IF(AND(W2="ppm";L2-INT(L2)>0;L2<100;);"FALSE9";
	IF(OR(AND(W2="ppm";K2="GOOD";L2<1000);AND(W2="%";K2="GOOD";L2<0,1));"FALSE10";
	IF(OR(AND(W2="%";OR(K2="POOR";K2="FAIR");L2<0,05);AND(W2="ppm";OR(K2="POOR";K2="FAIR");L2<500));"FALSE11";
	IF(AND(I2<>"";Y2="");"FALSE12";
	IF(AND(AC2<>"";AG2="");"FALSE13";	"GOOD"))))))))))))))
```

where

B2 = 'STRAT_TOPLAAG_AH'

C2 = 'STRAT_BASISLAAG_AH'

G2 = 'show_interpreter'

I2 = 'exact_measurement_depth_gas'

K2 = 'interpreted_gas_show'

L2 = 'total_HC_gas'

M2 = 'background_gas'

W2 = 'gas_unit'

Y2 = 'lithology_gas'

AC2 = 'exact_measurement_depth_oil'

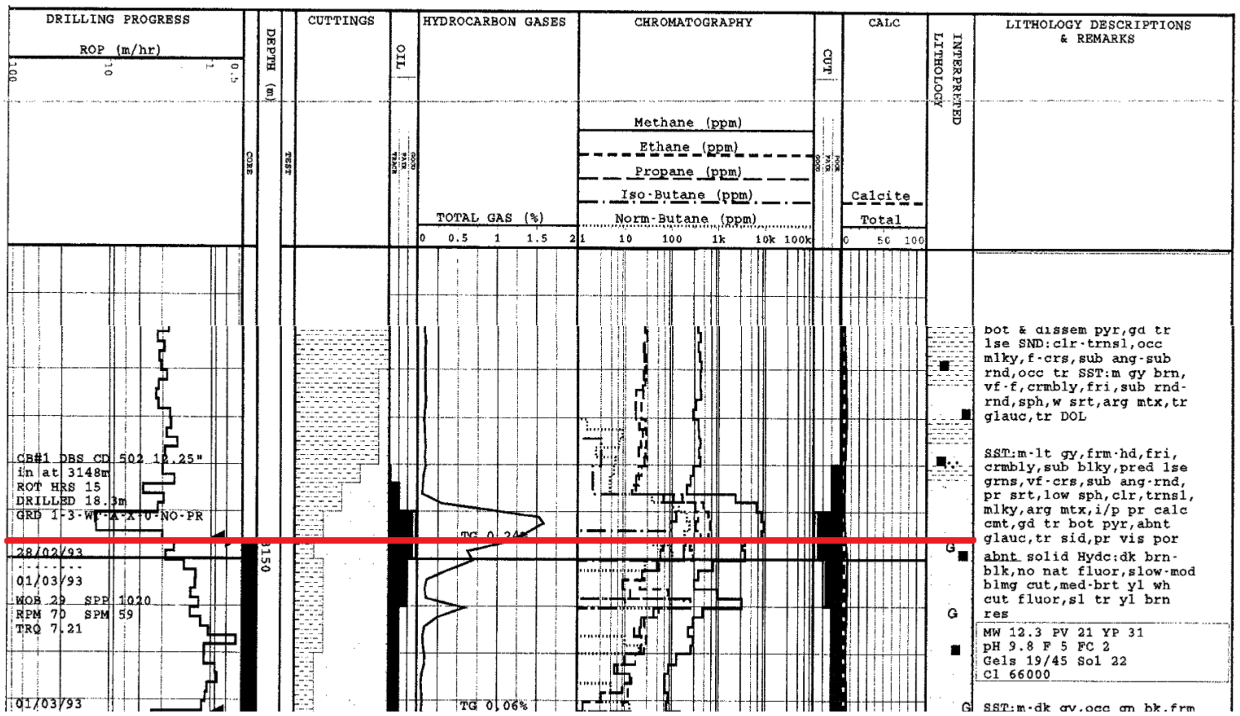
AE2 = 'oil_show'

AG2 = 'lithology_oil'

Appendix C ATLAS contributions

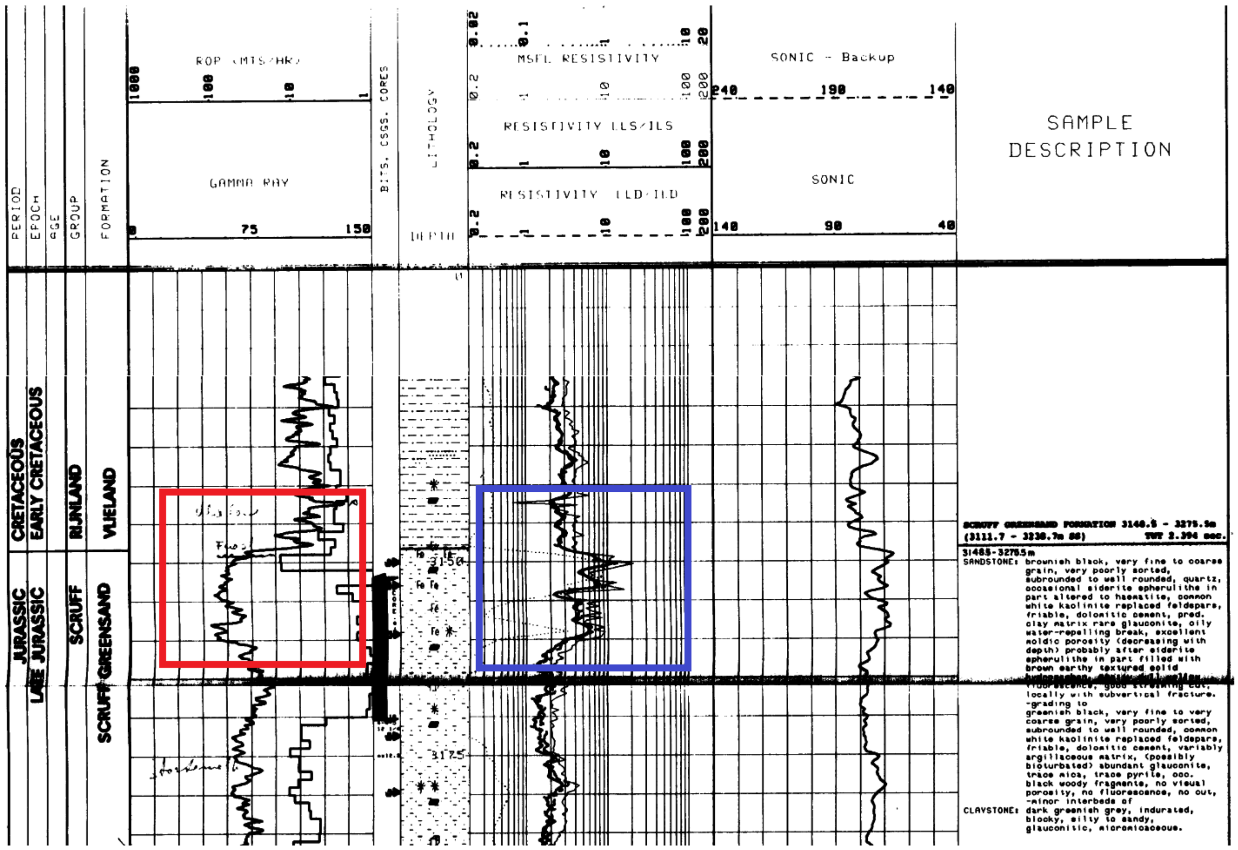
7. Gas peaks and oil shows located at stratigraphic boundaries

Gas peaks and oil shows that are located around the boundary between two stratigraphic units generally count towards the lowest stratigraphic unit. The idea is that shows are related to a reservoir-seal pair with the latter situated above the former. In some cases it is not possible to determine from the gas log to which unit a show belongs. In this case gamma ray measurements and resistivity measurements (often found on the composite log) can be used. E.g. the figure below shows a gas peak and oil show. The boundary between Lower Cretaceous Rijnland Group and the Upper Jurassic Scruff group has been picked by TNO at 3148,5 mAHD and cuts through the middle of the gasshow (red line). Moreover the maximum of the gas peak plots in the KNNC. From the cuttings, the boundary between the KNNC and SGGSS appears to be a gradual change from siltstone to sandstone. However, the bottom of the Cretaceous typically consists of low porosity and low permeable rocks in which these prominent shows are not expected. So, we consider the gamma ray and resistivity measurements shown in the second figure.



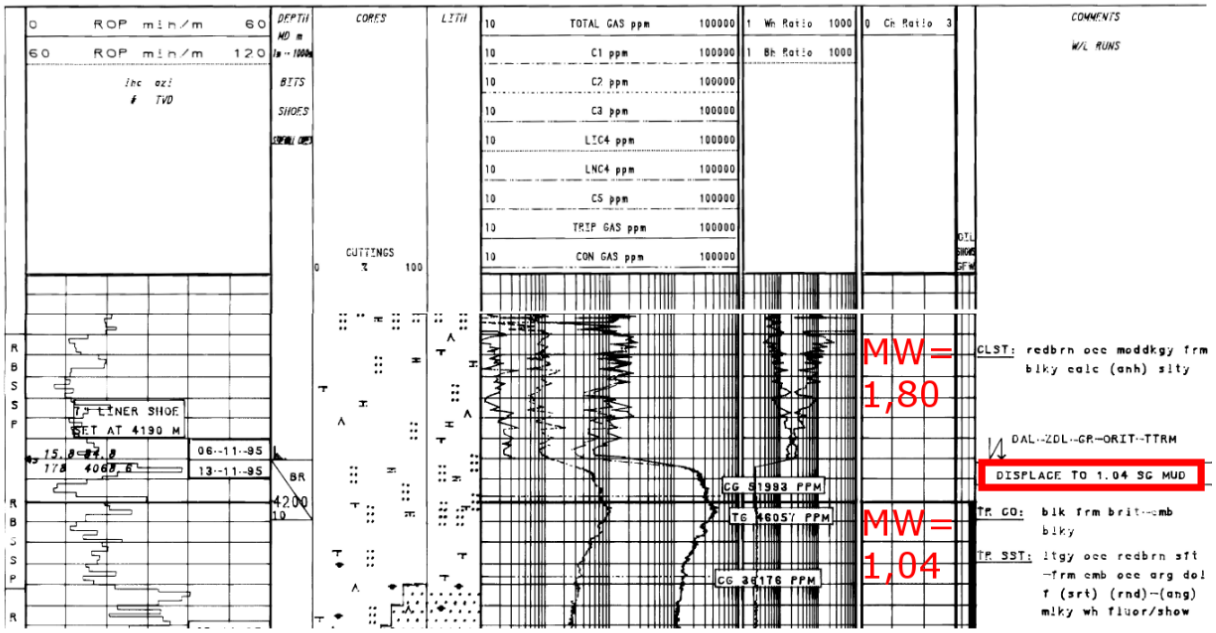
The red box in this figure shows a very sharp decrease in the gamma ray measurements over the stratigraphic boundary. Thus, the rock type changes from siltstone to sandstone (which has a much lower organic matter / potassium content and thus lower radioactive decay) over a small depth interval. In addition, the blue box shows that the resistivity increases sharply over the stratigraphic boundary. Pores filled with hydrocarbons have a much higher electric resistance than pores filled with brine.

For these reasons we can assume that the siltstone effectively traps hydrocarbons in the underlying sandstone. Therefore, the oil show and gas peaks observed are representative for the SGGSS.

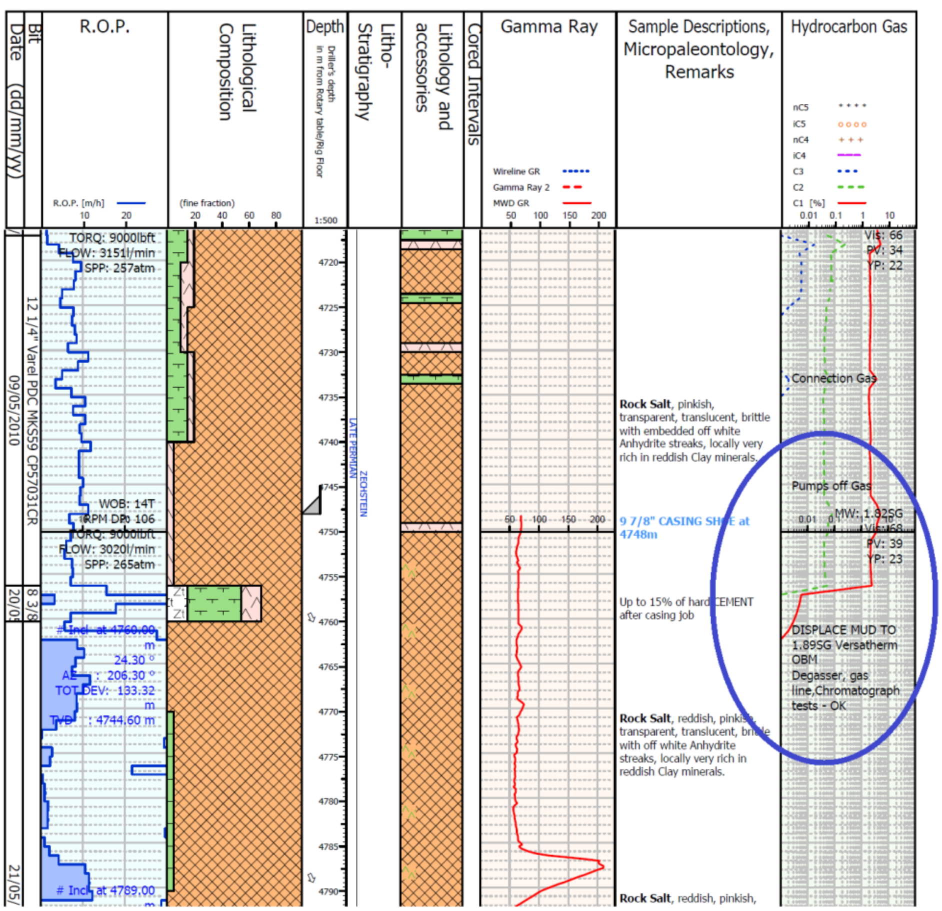


8. The effects of mud weight on gas chromatograph readings

A lower mud weight results in a lower pressure inside the borehole allowing more gas from the surrounding formation to enter the borehole. Naturally, this increases the gas readings by the chromatograph. A too high mud weight may result in mud loss to the formation and causes low gas readings. These effects are illustrated in the figures below. The first figure shows a sudden increase of the gas readings which is not associated to a lithology variation. Merely, the change in gas readings is caused by a reduction of the mud weight.



The second figure shows a sudden drop in measured hydrocarbon gases. In this case the drop is caused by an increase in mud weight. Before the mud weight was increased, hydrocarbon gas readings exceeded 1 percent which is very high for a rock salt (which has a very low porosity). Because absolute background readings depend on many variables (such as mud weight), we have to consider the PtBR to find HC shows. Thus, high gas readings do not necessarily mean there is a good show.



Appendix D Discrepancies between ‘interpreted_gas_shows’ and ‘raw_gas_shows’ explained

Appendix D.1

Explanations for changing ‘interpreted_show_classifications’ above the ‘green line’ in Figure 3.1: The red circle in the top left of Figure 3.1 is caused by a ‘gas_unit’ (ppm or %) mix up in borehole N04-02. The three stratigraphies represented by the orange NO SHOW-FAIR ratings are caused by wrong ‘interpreted_gas_show’ ratings (G10-03 and L04-06) and a typo in the ‘background_gas’ (L04-A-03). Also, several shows did not have a sufficiently high PtBR for their ‘interpreted_gas_show’ rating and have been downgraded.

Gas shows with a higher ‘interpreted_gas_show’ rating than ‘raw_gas_show’ rating explained			
‘raw_gas_show’	‘interpreted_gas_show’	Nr. of occurrences	Explanation
NO SHOW	POOR	3	Very high peak and background gas readings (3x)
POOR	GOOD	7	Very high peak and background gas readings (7x)
POOR	FAIR	12	• Show in NU (5x) • Very high peak and background gas readings (4x) • Fair show qualities but just poor gas readings (1x) • Well flowed (1x)
FAIR	GOOD	18	• Show in NU (7x) • Well flowed (1x) • Very high peak and background gas readings (10x)

Notes for the table above: shows in the NU require a lower gas peak for a certain rating because of the relatively high porosity. Also, shows with very high peak and background gas readings require a lower PtBR ratio for a certain rating.

Appendix D.2

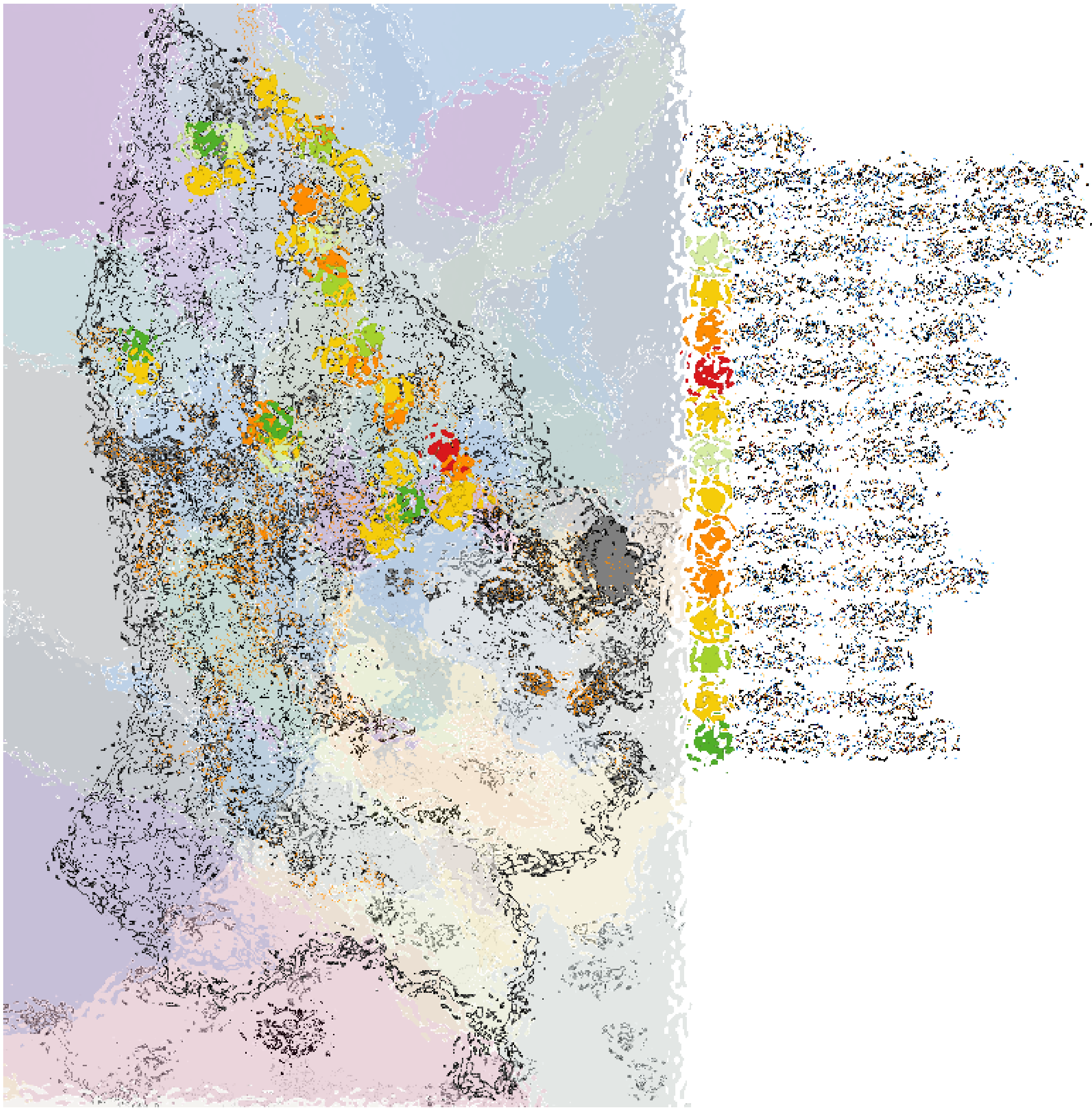
Potential missed pay represented by a GOOD ‘raw_gas_show’ rating and a NO SHOW ‘interpreted_gas_show’ rating						
Borehole	STRAT_ CODE	Lithology_ gas	Total_HC_gas	Background _gas	Initial interpreted _gas_show	Final interpreted _gas_show
E17-02	ROCLE	Claystone	1000	200	NO SHOW	POOR
F11-02	SGKI	Limestone	1000	100	NO SHOW	NO SHOW
F17-01-S2	RNKPS	Claystone	0,50	0,10	NO SHOW	NO SHOW
G17-03	NUBA	Clay	10000	2000	NO SHOW	POOR
L05-12-S1	RBMH	Claystone	0,88	0,10	NO SHOW	NO SHOW
L05-FA-103	RNROU	Claystone	1010	150	NO SHOW	POOR
L06-06	ZESA	Claystone	2000	100	NO SHOW	NO SHOW

Potential missed pay represented by a GOOD 'raw_gas_show' rating and a POOR 'interpreted_gas_show' rating in chalk, dolomite, limestone, sand or sandstone with a 'total_HC_gas' concentration larger than 1950 ppm

Appe

borehole	STRAT_ CODE	Lithology_ gas	Total_HC_gas	Background _gas	Initial interpreted _gas_show	Final interpreted _gas_show
E09-01	NU	sand/clay	3000	500	POOR	POOR
F05-04	CKEK	chalk	0,2	0,04	POOR	POOR
F08-01	ATWD	sandstone/ claystone	2050	300	POOR	POOR
L02-09	RBMVC	sandstone	11250	1000	POOR	POOR
L02-09	RBSHR	limestone	9150	800	POOR	POOR
L05-FA-102-S1	RBMH	sandstone	1950	80	POOR	POOR
L06-06	ROSLL	sandstone	11000	1400	POOR	POOR
L06-06	DC	sandstone	20000	4000	POOR	POOR
L06-07	CKTXM	limestone	5975	800	POOR	FAIR
L06-07	SGSKT	sandstone	5410	1000	POOR	POOR
L07-06	ZEZ2H	limestone	0,32	0,03	POOR	POOR
N04-02	ZEZ1C	dolomite	0,9	0,1	POOR	POOR
Q07-04	RNMUL	dolomite	2100	250	POOR	POOR

Appendix E Locations of the 41 boreholes present in both the EBN and Panterra datasets



The color scheme is based on corresponding show ratings. Green hues indicate similar classifications while yellow to red hues indicate increasingly dissimilar classifications.

Appendix F Major structural elements in the Netherlands

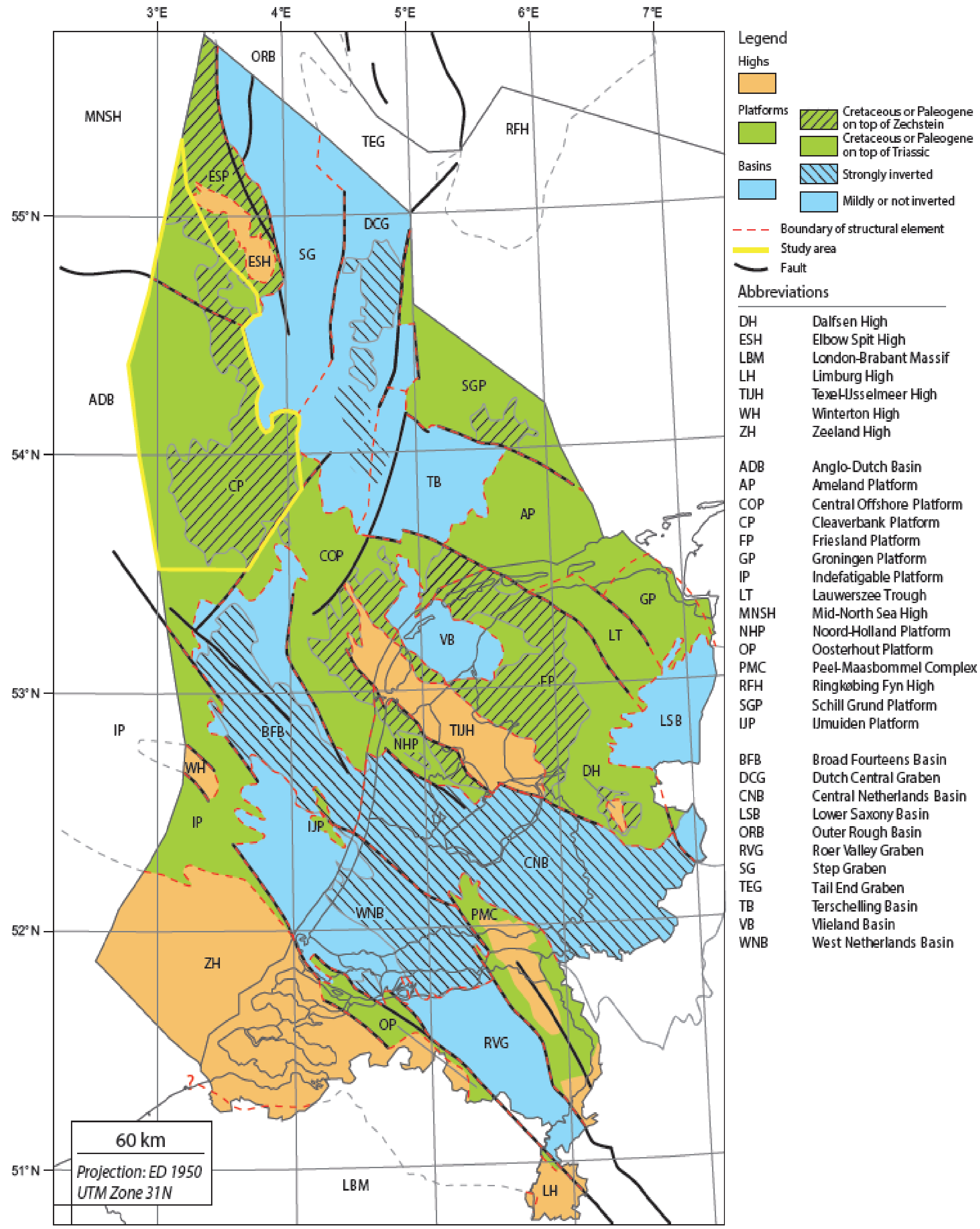


Fig. 1. Major structural elements in the Netherlands with the location of the study area. The outline of the study area is nearly the same as the outline of the NCP-2D subarea (not shown).

Source: (Fattah, Verweij, Witmans, & ten Veen, 2012)