The layers and their properties inside the Delft sandstone formation

By Jeroen van Eldert

Bachelor Project

Name:	Jeroen van Eldert
Supervisor:	K.-H. Wolf
Grade:	3rd grade, student Bachelor Applied Earth Science
Student number:	1262335
Duration:	7 weeks

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Introduction

In November 2007 The Mijnbouwkundige Vereeninging launches a plan to use geothermic energy to heat the University of Technology Delft and some surrounding homes. After the notification of the public, the faculty of applied earth science and the Stichting DAP worked together to find more information of the location and that the parameters which are going to be uses for the project. Many students will do, bachelor and/or master thesis to do the research for the project.

My bachelor thesis is applying to the correlation between wells and layers inside the Delft sandstone formation and the properties. The well data which is used for this thesis are gathered in the Moerkapelle-field. This field explored and exploited by the NAM as an oilfield. We used the data of the Moerkappele field because there is almost no data available of the Delft sandstone in the Delft area. The logs which are taken form the MKP (Moerkapelle-boreholes) are made in the 1950s. With these data I hope it will be possible to define several clay and sandstone layers in the Delft sandstone, and to correlate these. I will also use the log data to determine the different properties of the defined layers.

The importance of this project is that it will be used for the Delft Aardwarmte Project (Delft Geothermic Project). In this project hot water from an aquifer which lays two kilometer below the surface. The heated water will be, hopefully, used to heat up houses and some university buildings of the University of Technology Delft.

Data

The first thing I did was a search on the driller's information and especial to have a look at the height of the logger's and drilling depths. These are displayed in Table 1.

Well number	16	15	14	13	12A	12	11	10	9A
Referring Depth	Rotary Table	Rotary Table	Rotary Table	Rotary Table	Rotary Table	Rotary Table	Rotary Table	Rotary Table	Rotary Table
Referring Drilling Depth	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Result of drilling	Oil	Oil	Oil	Oil	Oil	Oil	Oil	Oil	Oil
Platform Height	0 m	1 m	1 m	2 m	2 m	2 m	2 m	3 m	2 m

Table 1: Logger's information (source www.nlog.nl)

After that I checked the log data and compared the peaks of the Gamma-ray, Neutron porosity, Bulk density and a Restively log, so they were indeed in line. I also had some information about the hydrocarbon saturation of the MKPs.
When the data is check we used the measured depth to do the calculations.

In order to find the Delft sandstone formation I used the file "Put info.xls". This file displays the formations in the bore holes. Due to this information we can find the Delft sandstone formation in all boreholes except in MKP 15. Table 2 shows the top and bottom of the Delft sandstone formation in each well.

Well number	MKP 16	MKP 15	MKP 14	MKP 13	MKP 12A	MKP 12	MKP 11	MKP 10	MKP 9A
Top Delft sandstone	-976	-	-774	-863	-778	-857	-761	-628	-805
Bottom Delft sandstone	-1097	-	-796	-909	-828	-958	-800	-678	-845

Table 2: The Delft sandstone in each borehole, in true vertical depth.

Gamma-Ray

In order to calculate the shale content, with this shale content we will pick different layers in the Delft sandstone Formation out of a plot of the V_{shale} and the measured depth values. To calculate the Vshale we used the maximum and minimum values of the Gamma-Ray log from the Rodenrijs, Delft sandstone and Alblasserdam Formation. The formula used is displayed below.

$$V_{shaleGR} = (GR_{measured}-GR_{min}) / (GR_{max}-GR_{min}) \qquad (1)$$

$V_{shaleGR}$: Shale content of the data point in the Gamma-Ray log
$GR_{measured}$: The GR (in API units) measured at that specific data point
GR_{min}: The minimum GR value (API units) measured in the well
GR_{max}: The maximum GR value (API units) measured in the well

Out of the graph I found ten different layer in the Delft sandstone formation, these layers where all found in the majority of the logged boreholes. The maximum and minimum GR value is showed in table 3.

well	MKP 16	MKP 15	MKP 14	MKP 13	MKP 12A	MKP 12	MKP 11	MKP 10	MKP 9A
Total max	158,49	145,85	173,25	269,81	199,24	134,13	134,13	158,21	297,25
Total min	14,28	16,47	15,04	9,54	13,94	14,3	17,3	17,94	10,77
Max in clay/shale	122,26	-	129,88	182,05	155,09	134,13	132,26	110,09	173,22

Table 3: The maximum and minimum Gamma-Ray value in each well

We know that the sediment deposit is formed in the cretaceous. In order to compensate the radioactive decay we will use the old rock equation, which is displayed below.

$$V_{shale} = 0.33*(2^{2*VshaleGR} - 1) \qquad (2)$$

$V_{shaleGR}$: Shale content of the data point in the Gamma-Ray log
V_{shale}: Original shale content of the deposit at the data point

Neutron porosity

After I picked the layers in the Gamma-Ray log, I had to do a check up for the reliable of this picking and I did the same procedure with a neutron porosity plot and I found out I picked the same layers as I picked a the V_{shale} plot.

Form the information and calculations already gathered we can calculate the effective porosity of the different data points. In order to do that I needed the shale porosity and I used the 100% locations (derived from the V_{shale}) to find that porosity for each well. Due to the use of the shale porosity, the neutron porosity and the V_{shale} I could calculate the effective porosity with the formula displayed below.

$$\Phi_{effective} = \Phi_{neuton} - V_{shale} * \Phi_{shale} \qquad (3)$$

$\Phi_{effective}$:	Effective porosity
Φ_{neuton}:	Neutron porosity
V_{shale}:	Shale content
Φ_{shale}:	Shale porosity

Bulk density

If we take the Bulk density and the Neutron porosity form the Delft sandstone and the shale layers of the Rodenrijs and Alblasserdam Formation (GR value higher than 90 API units). We can make a FDC-CNL plot, and from this plot we gas see there is no gas in side the formation (no points above the clean sandstone line) and we also can derive the shale points in each well. The clean sandstone line is got from the petrophisics paper (figure 9A.5). An example of the plots is showed below, the rest is displayed in appendix D.

Well number	Shale porosity
MKP 16	0,32
MKP 14	0,32
MKP 13	0,32
MKP 12A	0,32
MKP 12	0,32
MKP 11	0,32
MKP 10	0,32

Table 4: The shale porosity in each well

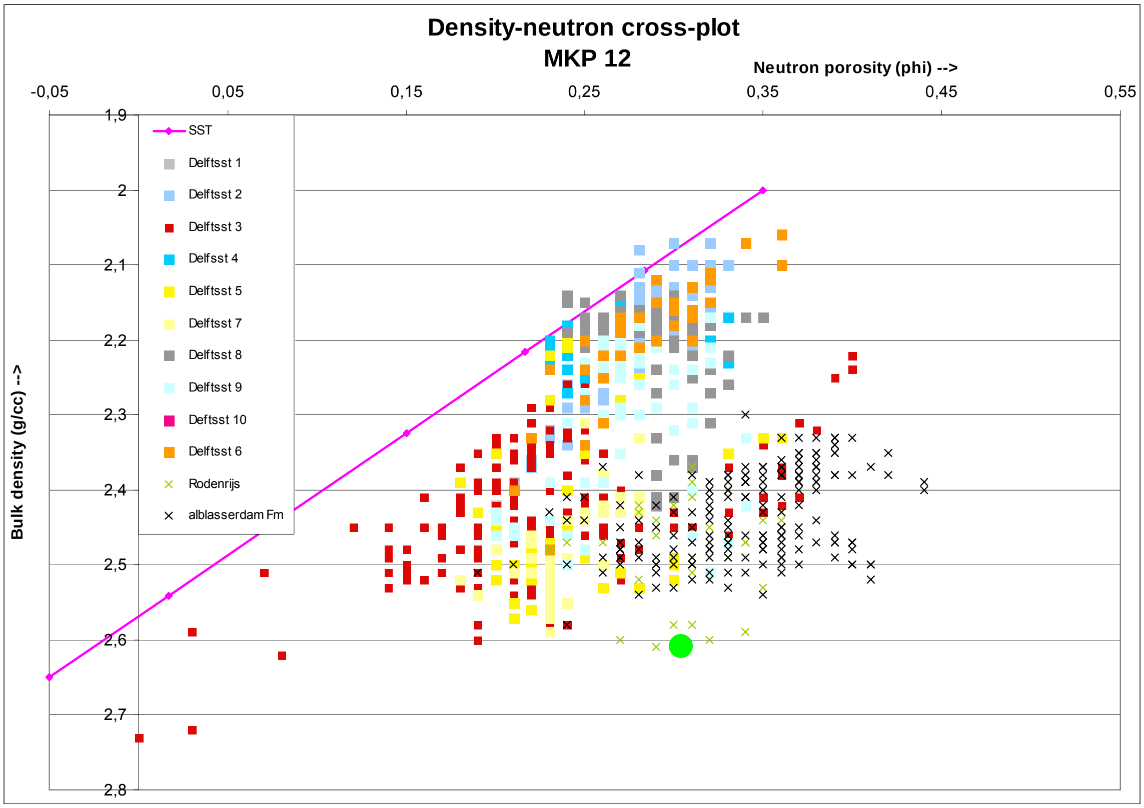


Figure 1: The FDC-CNL from the Delft sandstone and the shale layers of the Rodenrijs and Alblasserdam Formation plots of well MKP 12 of the Moerkapelle field. The others are shown in the appendix

I also used this bulk density to find the coal seams under the surface in the Moerkappelle area. As we know the coal seams are low in density and have a low radioactive content, so we need data points which have a bulk density below 1.8 grams/cc and a low GR-value.
The purpose of the coal seems was to use them as guide layers, to connect the bore holes. As you can see in the table below, they were only present in two wells, the MKP 14 and MKP 9A, and in these wells they were not at the same formation, above the Delft sandstone formation in MKP 9A, and under need the Delft sandstone formation in MKP 14.
The seams I found are displayed in the table below.

Well #	Measured depth from [m]	Measured depth to [m]	Average Bulk density [g/cc]	lowest bulk density [g/cc]	Average GR [API]	Lowest GR [API]
14	2651.150	2651.303	1.80	1.79	123	117
	2744.572	2745.029	1.72	1.62	84	65
	2745.791	2746.096	1.77	1.70	122	118
	2751.582	2752.039	1.66	1.59	66	38
9A	308.415	309.524	1.84	1.79	65	62
	470.459	489.204	1.72	1.58	75	63

Table 5: The coal seams in the MPKs

Resistivity Log

One important parameter in my calculation is the water resitivity of the water in the formation. With the data gather by the NAM it was hard to calculate the water resistivity. In the first place I tried to get a estimation of the range of the resistivity. In order to get an idea of the value I calculated the resistivity from the table concerning the water quality of De Lier and the Lower Cretaceous in The Hague. The value of the calculations of the resistivity of this water was around 0.043 Ωm, the table of the water quality and the resistivity is shown below. To get this calculation I had to estimate a temperature (or a temperature gradient and a depth). I also had to convert the solved ions to Na- and Cl-equivalences with this information I could make an estimation of the resistance of the formation water.

De Lier					Lower Cretaceous			
Ion	(aq) [mg/L]	Na^+ & Cl^- eq. [mg/L]	multiplier		Ion	(aq) [mg/L]	Na^+ & Cl^- eq. [mg/L]	multiplier
Na^+	36300	36300	1		Na^+	31000	31000	1
K^+	200	190	0,95		K^+	130	123,5	0,95
Ca^{2+}	3600	3132	0,87		Ca^{2+}	7000	6090	0,87
Mg^{2+}	800	1424	1,78		Mg^{2+}	900	1602	1,78
Sr^{2+}	580	580	1		Sr^{2+}	200	200	1
Ba^{2+}	35	35	1		Ba^{2+}	40	40	1
Fe^{2+}	33	33	1		Fe^{2+}	0	0	1
Cr	55000	55000	1		Cr	62000	62000	1
SO_4^{2-}	150	127,5	0,85		SO_4^{2-}	280	238	0,85
H_2PO_4	20	20	1		H_2PO_4	0	0	1
H_4SiO_4	60	60	1		H_4SiO_4	0	0	1
H_2CO3	20	7	0,35		H_2CO3	260	91	0,35
TDS					TDS			
total NaCl eq.		96908,5			total NaCl eq.		101384,5	
R_w	0,045	ohm*m			R_w	0,041	ohm*m	

Table 6: The R_w of De Lier and Lower Cretaceous

The first calculation done with the information of the MKPs was done with Archie at a shale content of less than 5% and complete water saturation. The values for R_w gather by this calculation was highly flexible and had a maximum of 29 Ωm (MKP 10) and a minimum of 0.059 Ωm (MKP 12), these values were far more higher than expected. So a used another formula in which we stated a way from the areas with hydrocarbons and used a compensation for the shale component. The formula used for this calculation is displayed below.

$$R_w = (R_t - V_{shale} * R_{shale}) * \Phi_{eff.}^{m} \quad (4)$$

R_w: Water resistivity (Ωm)
R_t: Measured resistivity (Ωm)
V_{shale}: Shale content
R_{shale}: Shale resistivity, the resistance of a 100% shale layer (Ωm)
$\Phi_{eff.}$: Effective porosity
m: The formation cementation factor

The formula gave me variations of the values from 0.008 Ωm to 0.033 Ωm. But these values were from gathered from the complete well and so from different formations.

In order to get one R_w I made a Log(R_t)-$phi_{Neutron}$ plot, which is displayed below, in order to make this graph I removed the outliners because you always will have them and they will disturb the data set, so it is allowed to remove 10% of you data set with the reason that they are outliers. From this plot I determined the overall R_t, if we use Archie 1 we can calculate the R_w.
So in the Delft sandstone formation the R_w is 0.137 Ωm.

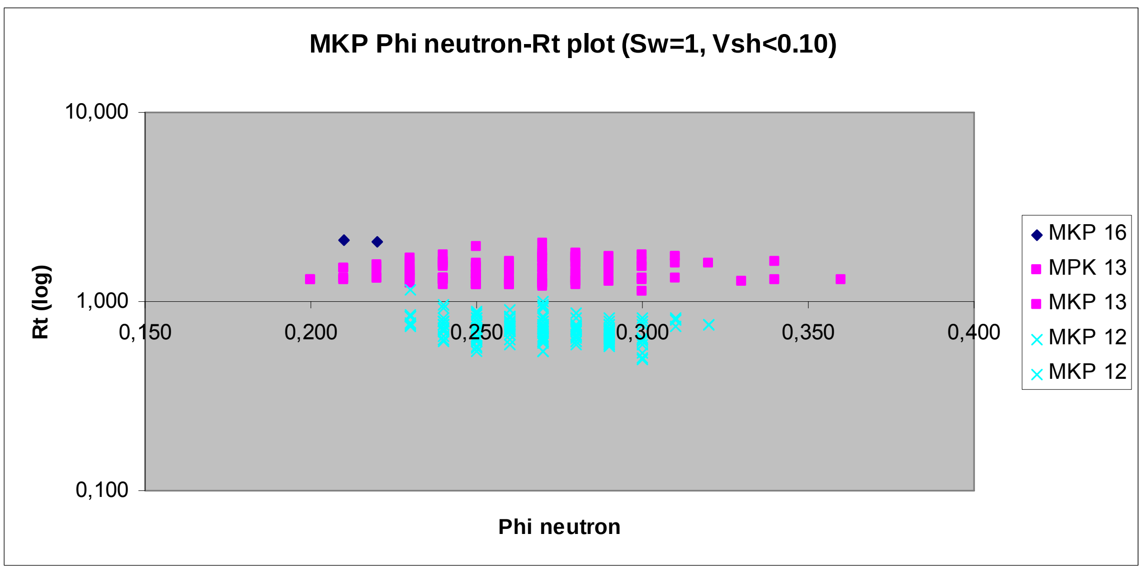


Figure 2: $\Phi_{neutron}$-Rt plot

After this calculation I got a kind of reliable of water resistance to do my water saturation calculations up on. So I used the Indonesia formula (4). The out come of this formula is display in table 7. We also got the hydrocarbon saturation form the NAM which is measured during the 1950s. With this S_{hc} was it possible to calculate the S_{wNAM}. The out come is displayed in the same table. And if we compare the NAM values with our own it easy to see that the values from the NAM are twice as large as my values. A possible explanation for this difference could be a decision of NAM to choose a cut-off. The NAM would probable used a cut-off in the 50s to measure the S_{HC} and S_w. The differences between the values could also been caused by the way of measuring and/or

calculating the S_w by the NAM during that time. This would also explain the differences between the NAM values and my own in Appendix C.
The deviation of the NAM values and my own is the highest in the clay or shale bearing layers. So I suspect that the clay content has an important influence on the differences between my calculations and the NAM measurements. I possible explanation could be the effect of shale and clay minerals, including ions, on the resistivity measurements. If the resistivity of layers with a high shale content are not corrected they will give a lower R_t and so a different R_w and S_w.

$$C_t^{0.5}=\Phi_{eff}^{(m/2)}*S_w^{(n/2)}*C_w^{0.5}+V_{shale}^{(1-Vshale/2)}*S_w^{(n/2)}*C_{shale}^{0.5} \qquad (5)$$

C_t: Measured conductivity (Ωm^{-1}) ($1/R_t$)
$\Phi_{eff.}$: Effective porosity
S_w: Water saturation
C_w: Water conductivity (Ωm^{-1}) ($1/R_w$)
V_{shale}: Shale content
C_{shale}: Shale conductivity (Ωm^{-1}) ($1/R_{shale}$)
m: Cementation factor (1.8)
n: Saturation exponent (2)

If we rewrite this formula we will get:

$$S_w=(C_t^{0.5}/(\Phi_{eff}^{(m/2)}* C_w^{0.5}+V_{shale}^{(1-Vshale/2)}* C_{shale}^{0.5})^{(2/n)} \qquad (6)$$

Well	Sw	Sw NAM
MKP 16	0,724	0,855
MKP 14	0,369	0,383
MKP 13	0,840	0,961
MKP 12A	0,357	0,275
MKP 12	0,850	0,984
MKP 11	0,312	0,523
MKP 10	0,124	0,434

Table 7: The water saturation of the Delft sandstone formation in each well

In MKP 10 we see a big difference between my calculation and the one done by the NAM. As we know there are a lot of problems with this well so there is probably something wrong with the gathered data.

Volume evaluation

In the Gamma-Ray chapter we calculated the V_{shale} so with this value it is possible to calculate the Net sand and shale. In order to do this I made different scenarios of the Net sand and shale at different cut-offs starting with 5% shale up to 40% shale in steps of 5%. To calculate the Net sand and shale I multiplied the number of values above (or under need) the cut-off by the distance between the data points (distance between the data points had variations from 10 to 15.3 cm. After using the measured depth, I converted the values to the true depth. After that I choose a cut-off of 40 % shale. The cut-off of 40% is choose because we will still have a fair porosity but the clay inside that part of the formation will have a major influence on the underground water flow. The values of the net sand and the net shale are displayed in the table below. The Net reservoir is calculated by the Net sand times the concession area which is 16.94 km^2, the surface map of the area and the concession is shown in appendix E.

MD	Shale cut-off: 40%								
MKP	16	15	14	13	12A	12	11	10	9A
net sand	115.20	0.00	16.46	58.67	44.80	87.48	48.01	57.00	46.48
net shale	6.30	0.00	6.55	0.31	7.10	16.00	4.42	4.42	0.00
net total	121.50	0.00	23.01	58.98	51.90	103.48	52.43	61.42	46.48

Table 8: The net sand and net shale at measured depth

TVD	Shale cut-off: 40%								
MKP	16	15	14	13	12A	12	11	10	9A
net sand	114.72	0.00	15.41	45.75	43.17	85.38	35.71	46.40	40.00
net shale	6.27	0.00	6.14	0.238	6.84	15.62	3.29	3.60	0.00
net total	120.99	0.00	21.54	45.98	50.01	101.00	39.00	50.00	40.00
Net/gross sst.	0,95	0,00	0,72	0,99	0,86	0,85	0,92	0,93	1,00
Φeffective (sand)	0.121		0.187	0.228	0.221	0.223	0.215	0.202	
Stdev Φeffective (sand)	0.039		0.044	0.042	0.038	0.067	0.053	0.035	

Table 9: The net sand and net shale at true vertical depth, in the 40% cut-off scenario

So, with a 40% Vshale cut-off, we can conclude that the Delft sandstone has an average Net sand thickness of 58.7 meter with a standard deviation of 25.0 meter except in MKP 15 and MKP 14 (respectively 0.00 m and 15.4 m). To come to this value we used the spread sheet program Microsoft Excel, with the functions average and stdev (standard deviation). If we take MKP 14 and MKP 15 in account we have an average of 47.4 m and a standard deviation of 29.7 m.
Another important parameter for the reservoir is the Net sand over gross Delft sandstone; this is given in the table above.
The area of the concession (16.94 km^2) is already calculated in Gamma-Ray chapter, so is we use this we know we have a average field of $0.995*10^9$ m^3 sandstone with a standard deviation of $0.423*10^9$ m^3, (respectively $0.802*10^9$ m^3 and $0.503*10^9$ m^3, with MKP 14 and MKP 15). From the data we can calculate the weight average porosity which is 0.200

and has an average standard deviation of 0.045. So we multiply the measured porosity in each bore hole by the Net sand in that bore hole. The average standard deviation is calculated by taking the average of the standard deviation in the MKPs. If we use this to calculate the total volume of water we will get $199*10^6$ m^3 ($160*10^6$ m^3) water in the field.

If we take a worse case, where the Vshale has a mayor influence, way higher than the estimation of 40%, let's say a 20% shale cut-off. The values of the Net sand and Net shale are displayed in the table below. The average thickness of the sand in this scenario is 43.6 m (34.0 m with MKP14 and MKP 15) with an average standard deviation of 15.0 m (23.0 m). And has a porosity of 0.212 with a standard deviation of 0.052.
So in this scenario we will have a water volume of $156*10^6$ m^3 ($122*10^6$ m^3).

TVD	Shale cut-off: 20%								
MKP	16	15	14	13	12A	12	11	10	9A
net sand	64,04	0,00	0,86	36,95	38,25	65,00	27,44	41,44	32,26
net shale	56,96	0,00	20,69	9,03	11,75	36,00	11,57	8,56	7,74
net total	121,00	0,00	21,55	45,98	50,00	101,00	39,01	50,00	40,00
Net/gross sst.	0,53	0,00	0,04	0,80	0,77	0,64	0,70	0,83	0,81
Φeffective(sand)	0.144		0.177	0.237	0.230	0.254	0.236	0.209	
Stdev Φeffective (sand)	0.028		0.025	0.038	0.025	0.038	0.036	0. 027	

Table 10: 20% cut-off scenario

And a 60%, the most positive case, is displayed down here.

TVD	Shale cut-off: 60%								
MKP	16	15	14	13	12A	12	11	10	9A
net sand	121,00	0,00	19,12	45,98	46,24	100,70	38,43	49,75	40,00
net shale	0,00	0,00	2,43	0,00	3,76	0,30	6,57	0,25	0,00
net total	121,00	0,00	21,55	45,98	50,00	101,00	45,00	50,00	40,00
Net/gross sst.	1,00	0,00	0,89	1,00	0,92	1,00	0,85	1,00	1,00
Φeffective (sand)	0.118		0.179	0.228	0.212	0.208	0.210	0.192	
Stdev Φeffective (sand)	0.040		0.055	0.042	0.050	0.074	0.056	0.049	

Table 11: 60% cut-off scenario

If we take this case, where the V_{shale} has a minor influence, we take a very positive scenario. The average thickness of the sand (net sand) in this scenario is 63.2 m (51.3 m with MKP14 and MKP 15) with a standard deviation of 33.3 m (37.6 m). And has a porosity of 0.192 with an average standard deviation of 0.052.
So in this scenario we will have a water volume of $206*10^6$ m^3 ($167*10^6$ m^3)
If we use the values from the table to calculate the reserves we get a 20% cut off reservoir, a 40% cut off reservoir and a 60% cut off reservoir. These are given in the table.

Cut-off	20 % cut off	40% cut off	60% cut off
Rock volume	$0.739*10^9$ m^3	$0.995*10^9$ m^3	$1.070*10^9$ m^3
Water volume	$156*10^6$ m^3	$199*10^6$ m^3	$206*10^6$ m^3

Table 12: Rock volume and water volume

So as you can see gives the pessimistic value of the reservoir still a water volume of 156 million cubic meters.

Conclusion

Now we have defined the layers in side the Delft sandstone formation and know their properties. We can draw a conclusion of the Moerkapelle field.

In the chapter of volume evaluation we see, we will have probable reservoir with $199*10^6$ m^3 water, if we take a cut off of 40% shale. Suppose we have a production rate of 150 m^3 an hour, we will produce 1,314,000 m^3 per year. So with this reservoir we can produce for 151 years. If we take the most pessimistic water volume (so include MKP 14 and MKP 15) and a cut-off of 20% we can produce for more than 119 years, till the water from reservoir is completely used.
If we use the most favorable reservoir we can produce for more than 156 years before all the water have been used.

Literature

Dr. K-H.A.A. Wolf, 1999, Petrofysics

Schlumberger, 2000, Log Interpretation charts

Dresser Atals, 1972, Log data

Appendices

Appendix A: All logs and data

Appendix B: Layers in the Delft sandstone

Appendix C: The Delft sandstone in one figure

Appendix D: Summary of the layer properties

Appendix E: The FDC-CNL plots

Appendix F: The surface map of the Moerkapelle field

Appendix G: Flowchart of the bachelor theses

Appendix

In Appendix A give the complete logs which are used in this project.

Well	Gamma-Ray [API units]	Bulk Density [g/cc]	Neutron Porosity	Resistivity (total) [Ωm]	Hydrocarbon content (NAM)
MKP 16	V	V	V	V	V
MKP 15	V	V	V	V	V
MKP 14	V	V	V	V	V
MKP 13	V	V	V	V	V
MKP 12A	V	V	V	V	V
MKP 12	V	V	V	V	V
MKP 11	V	V	V	V	V
MKP 10	V	V	V	V	V
MKP 9A	V	V	X	V	X

Table 11: The logs in the boreholes

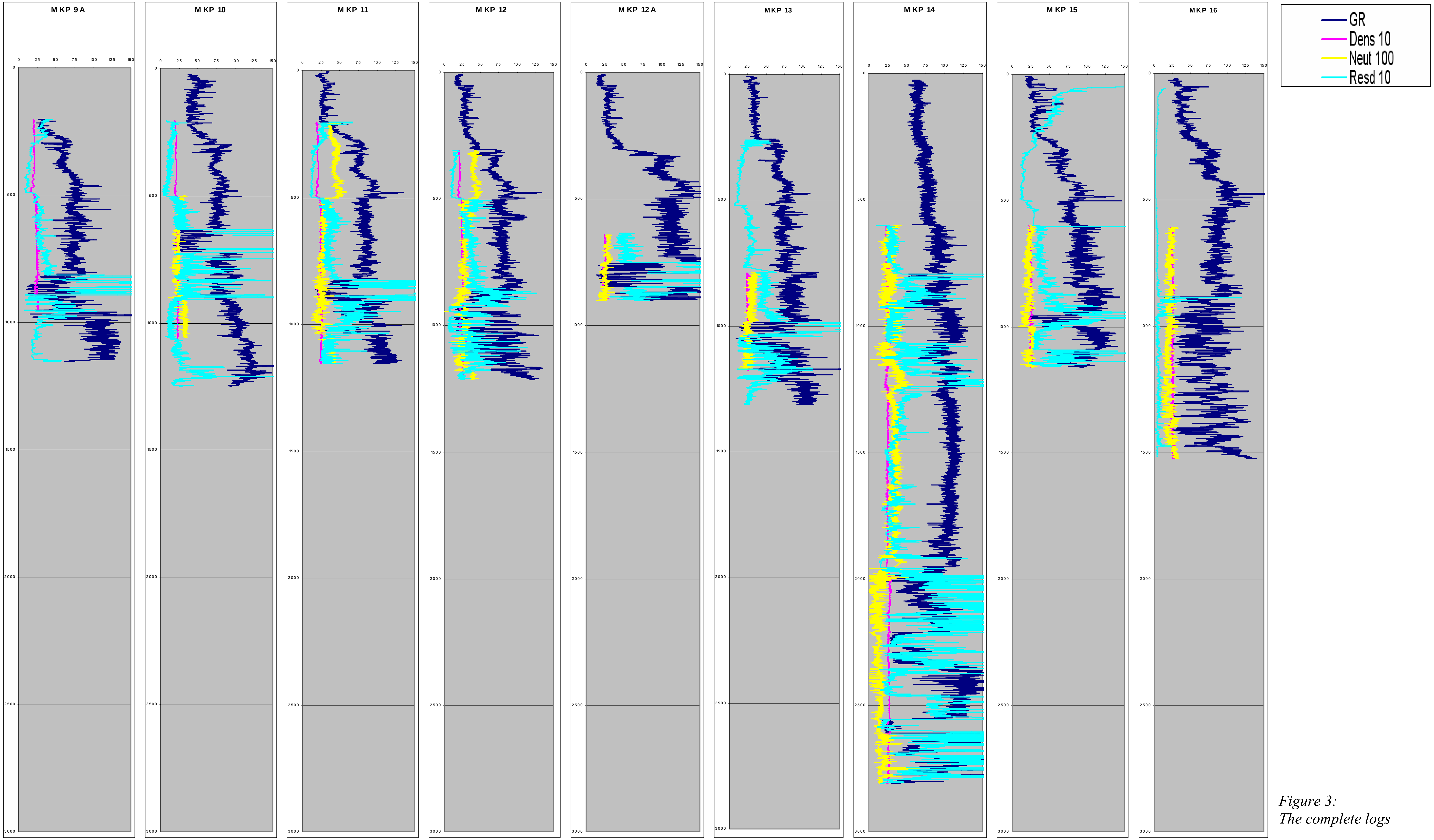


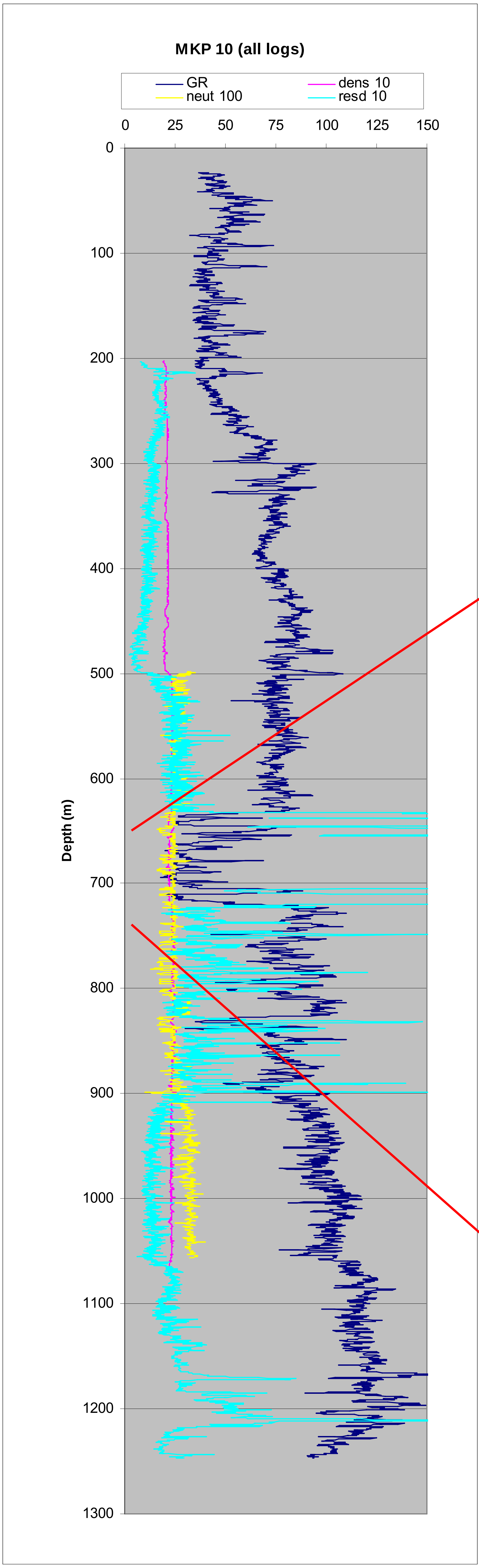
Figure 3:
The complete logs

Appendix B

Appendix B shows the logs of the Delft sandstone with the different layers displayed in a different color.

Layer #	color		definition
1		Gray -25%	top of Delft sandstone
2		pale bleu	first measurement of <0,15 after measurement with a value >0,15
3		red	>0,10
4		sky bleu	<0,10
5		yellow	>0,156 if progress to >0,23
6		orange	<0,202
7		light yellow	>0,202
8		gray -40%	<0,10
9		light turquoise	>0,10
10		pink	>0,18

Table 12: The layers and definitions



Seismic interpretation

layer		*GR*	*density*	*sonic*	*neutron*	*SP*	
Delft Sandstone	SLDND	↓	↓	↑	↑	↓	**Delfland FM**
Rodenrijs claystone	SLDNR	↑	↑	↓	↓	↑	
Alblasserdam Fm	SLDNA	↑	↑	↓	↓	↑	

Table 13: The values of the logs in the Delfland Fm

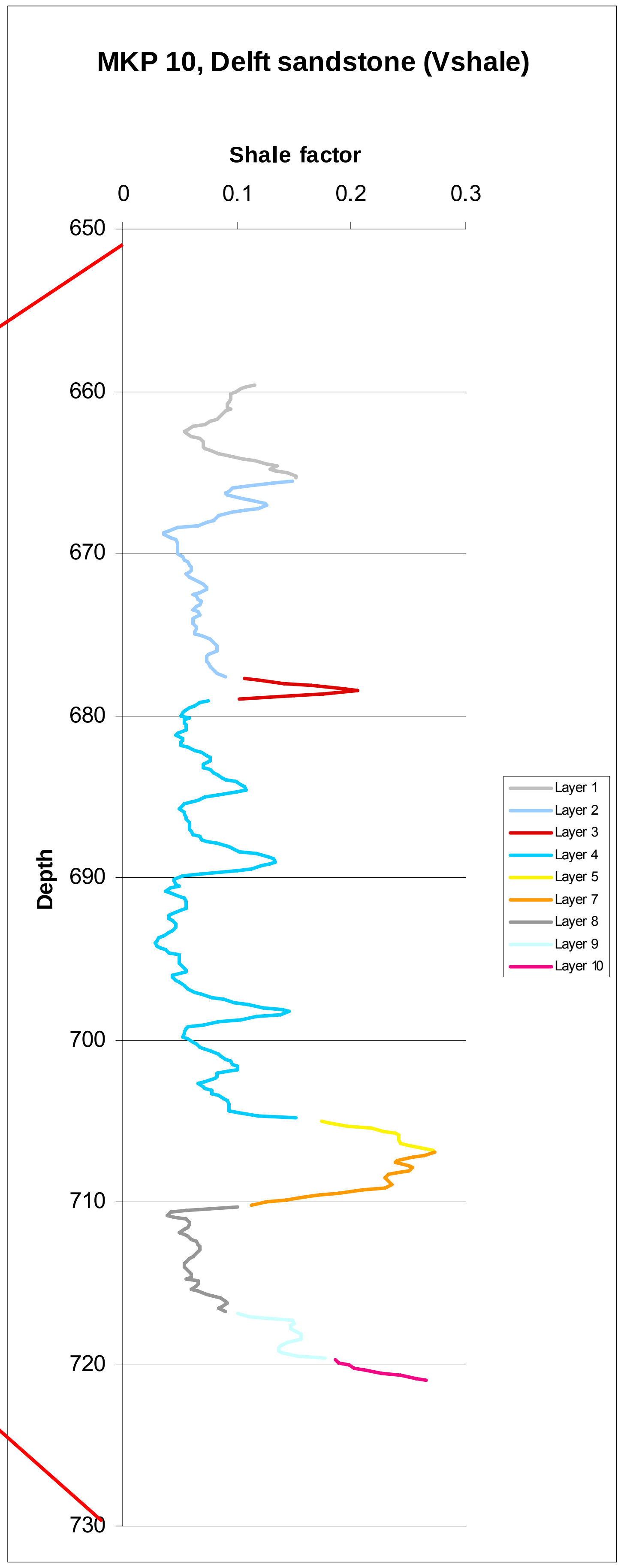
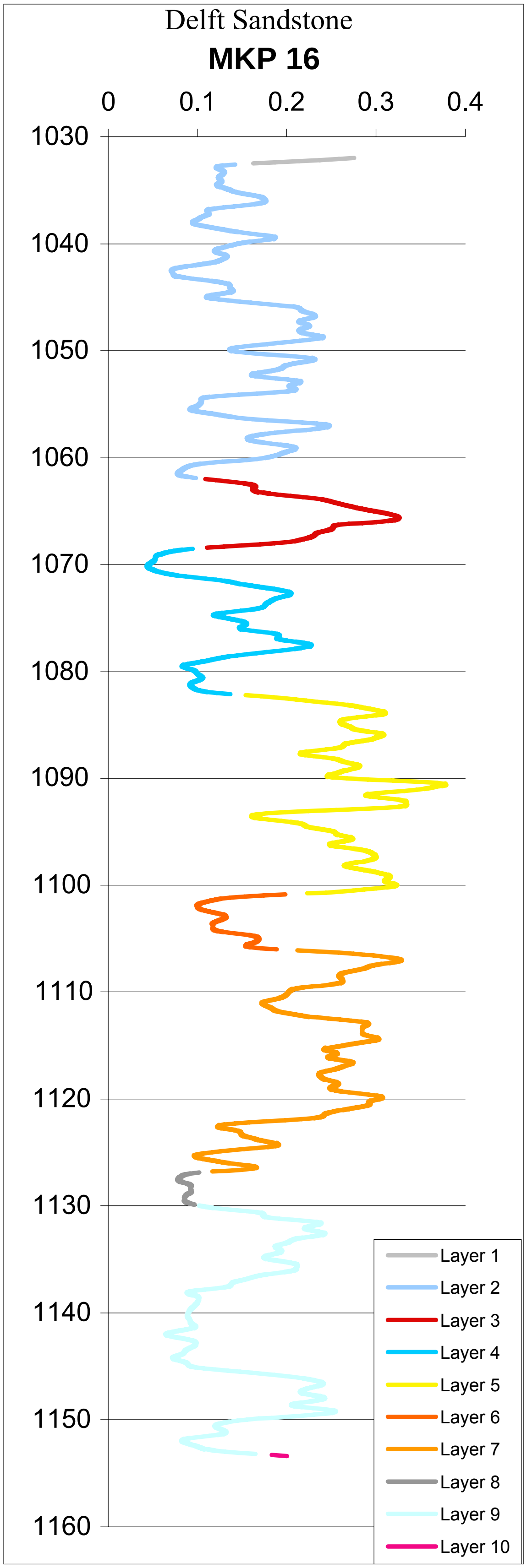


Figure 4: The Delft sandstone from the complete log.

Figure 3 is the complete bore hole logging of MKP 10 displayed. From the table we know that the Delft sand stone formation has a low Gamma-Ray and density log, and a high Neutron log. If we use this in formation we can find the Delft sandstone in the MKP 10.

On the next pages:

Figure 5: The layers in the Delft sandstone in the boreholes


Delft Sandstone
MKP 16
0
0.1
0.2
0.3
0.4
1030
1040
1050
1060
1070
1080
1090
1100
1110
1120
1130
1140
1150
1160
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Layer 2
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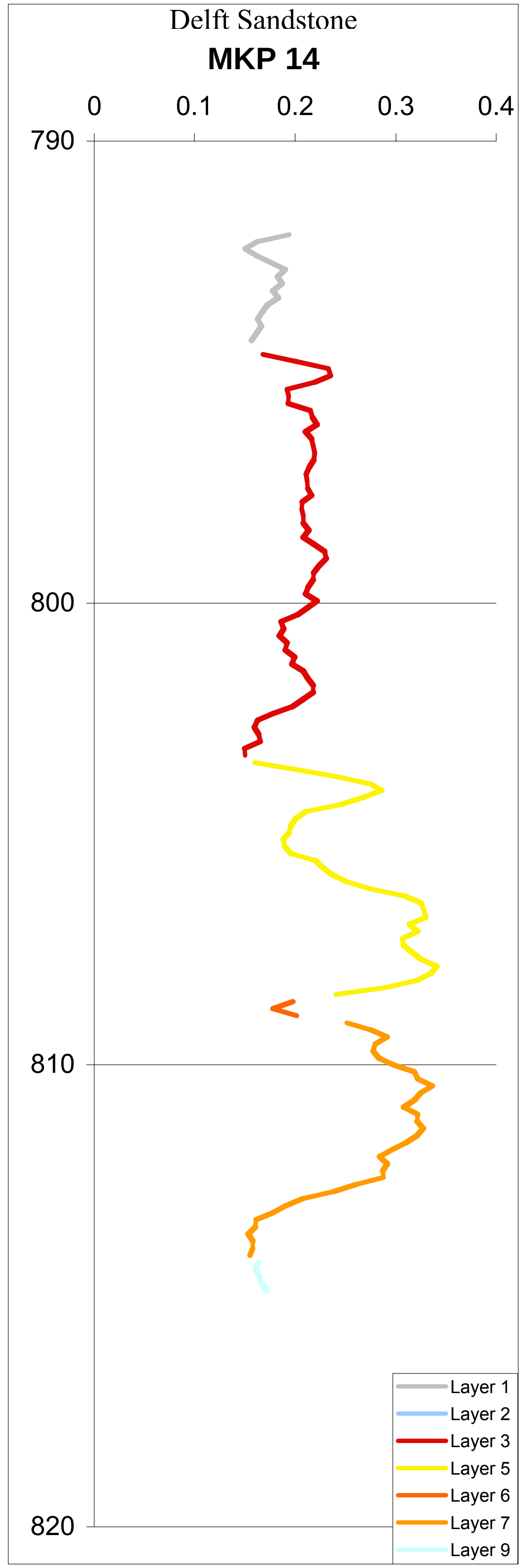
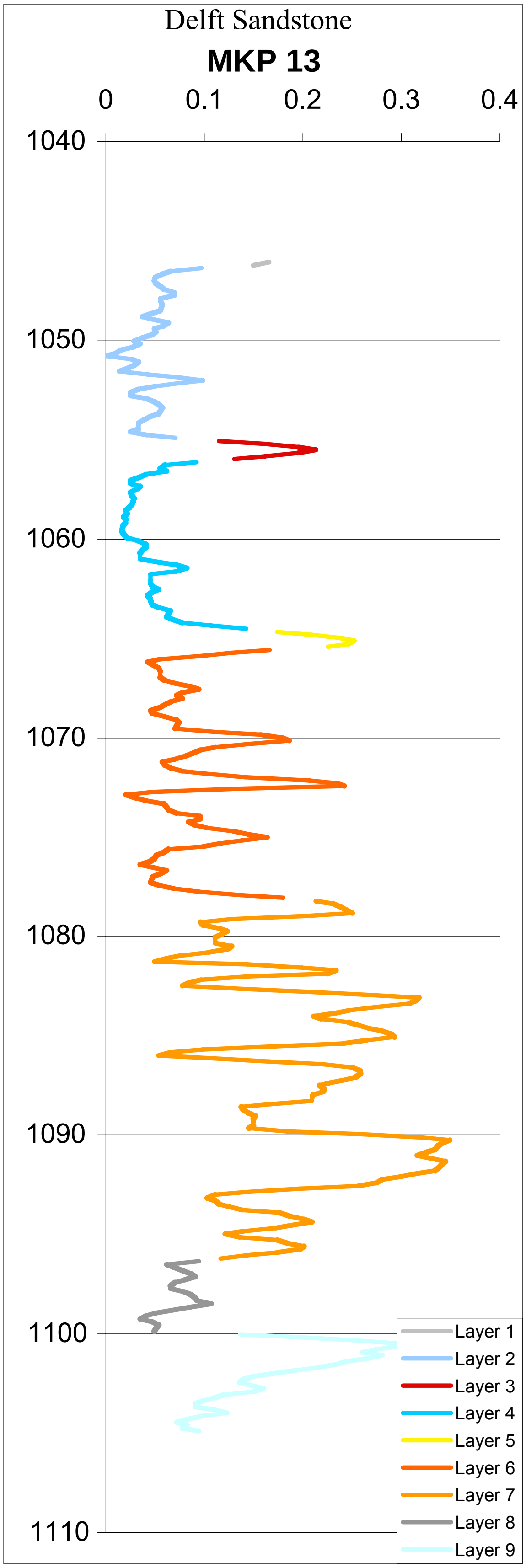
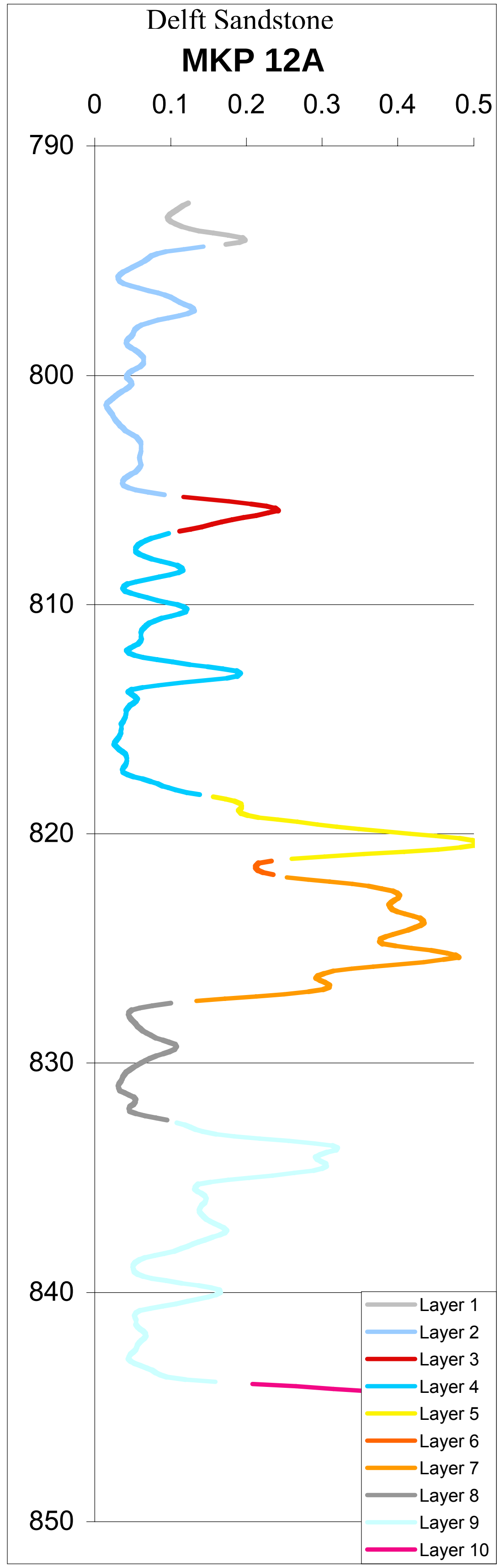
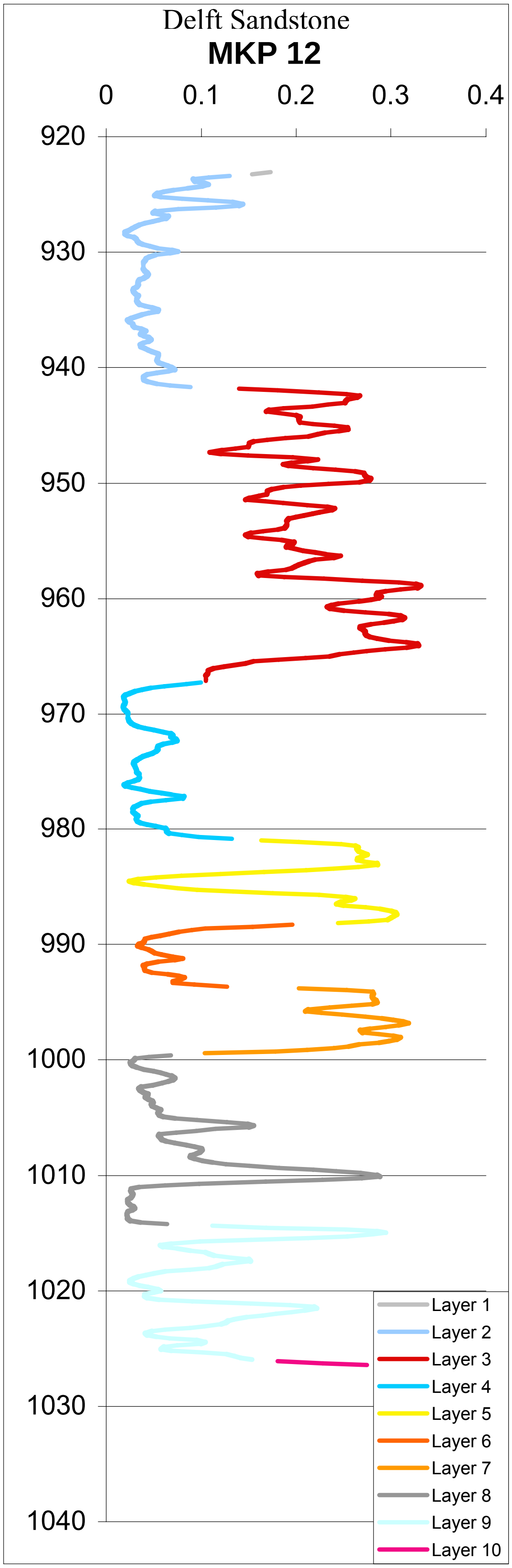
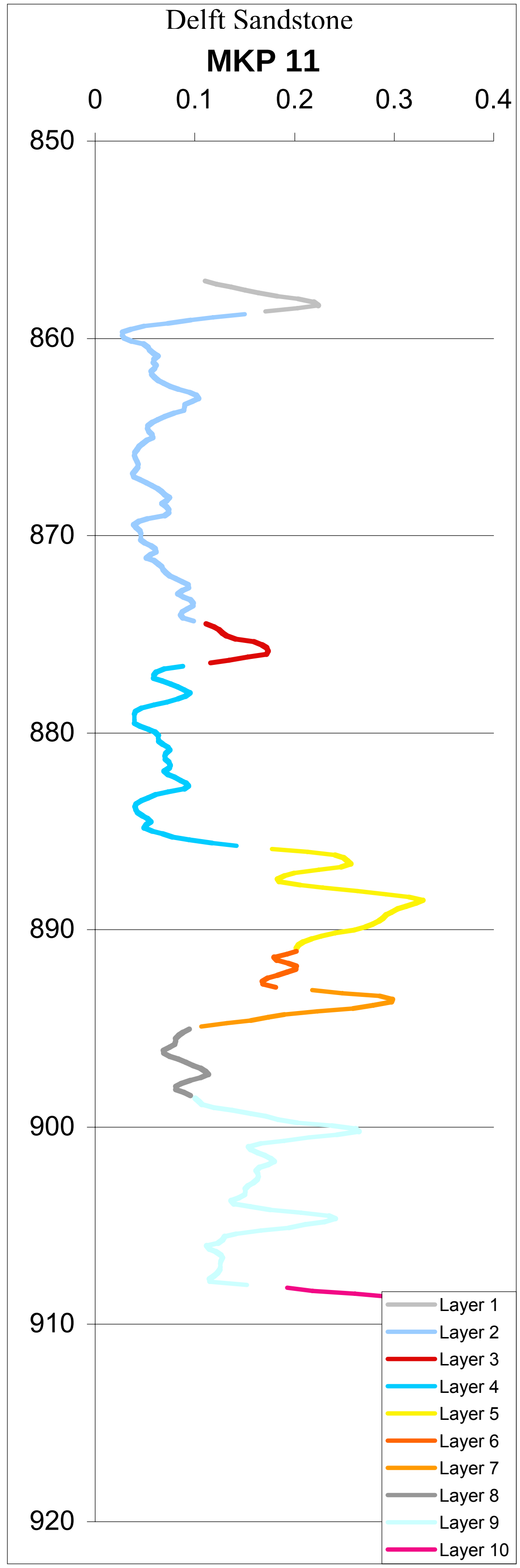
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
Layer 10

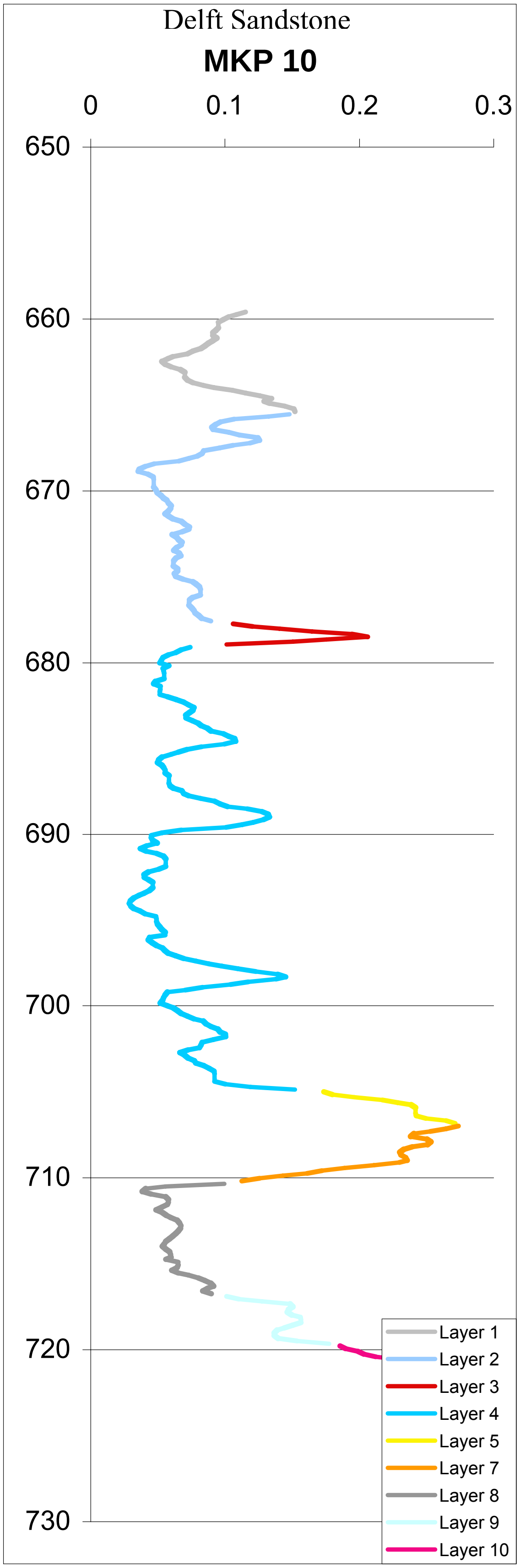

Delft Sandstone
MKP 14
0
0.1
0.2
0.3
0.4
790
800
810
820
Layer 1
Layer 2
Layer 3
Layer 5
Layer 6
Layer 7
Layer 9


Delft Sandstone
MKP 13
0
0.1
0.2
0.3
0.4
1040
1050
1060
1070
1080
1090
1100
1110
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9

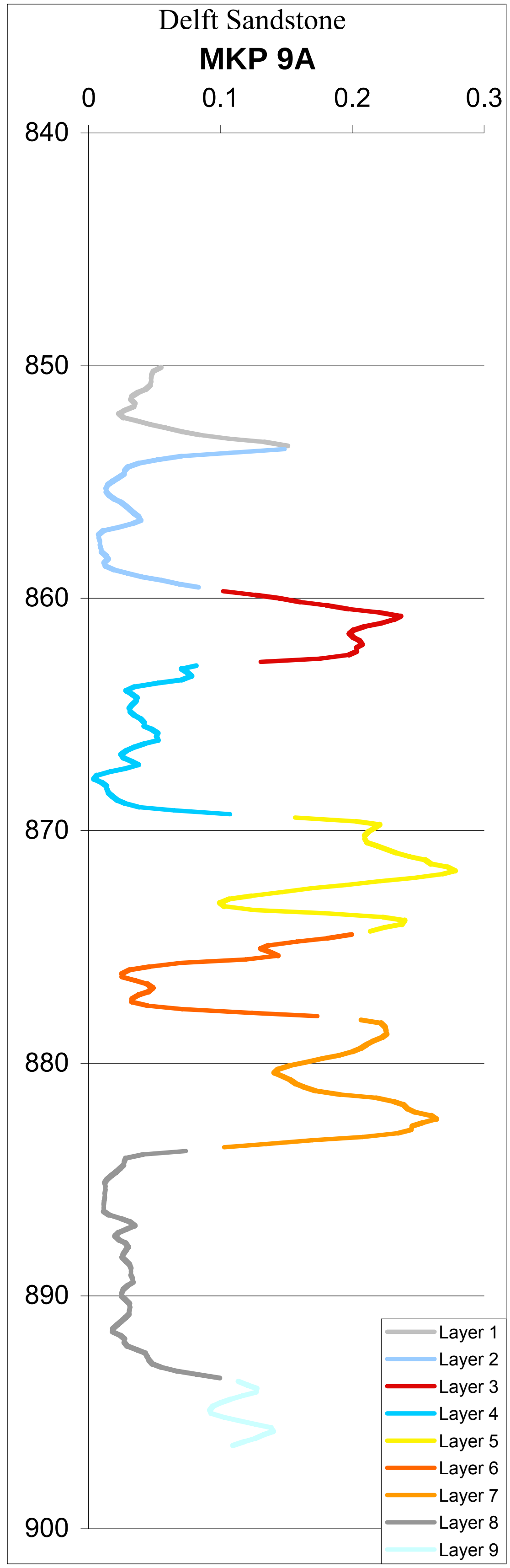

Delft Sandstone
MKP 12A
0
0.1
0.2
0.3
0.4
0.5
790
800
810
820
830
840
850
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
Layer 10


Delft Sandstone
MKP 12
0
0.1
0.2
0.3
0.4
920
930
940
950
960
970
980
990
1000
1010
1020
1030
1040
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
Layer 10


Delft Sandstone
MKP 11
0
0.1
0.2
0.3
0.4
850
860
870
880
890
900
910
920
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
Layer 10



Delft Sandstone
MKP 10
0
0.1
0.2
0.3
650
660
670
680
690
700
710
720
730
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 7
Layer 8
Layer 9
Layer 10



Delft Sandstone
MKP 9A
0
0.1
0.2
0.3
840
850
860
870
880
890
900
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9

Appendix C

The Delft sandstone layers in one figure.

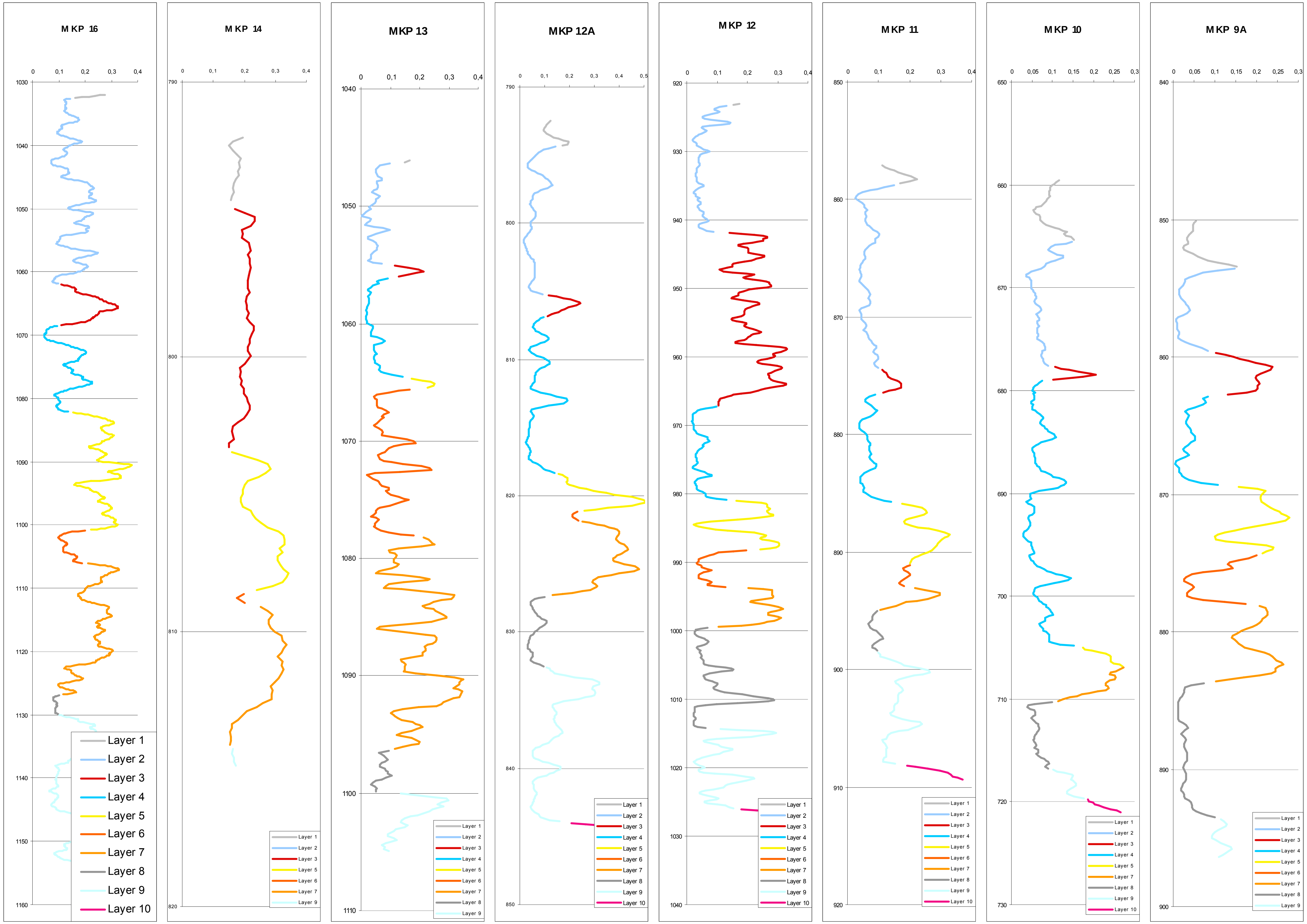


Figure 6: The Delft sandstone in one figure

Appendix D

A complete summary of all layers in the wells and their properties are displayed in Appendix C. They are sorted out for each well.

MKP16

layer	top (MD)	Bottom (MD)	Thickness (MD)	Thickness (TVD)	average GR	average Density	average Neutron	average resistivity	Vshale	shale porosity	effective porosity	Rw (self)	Sw (self)	Rw NAM	Sw NAM
1	1032.000	1032.600	0.600	0.598	73.550	2.538	0.020	5.695	0.240	0.320	0.120	0.137	0.597	22.650	0.794
2	1032.600	1062.000	29.400	29.279	53.903	2.434	0.195	4.441	0.157	0.320	0.144	0.137	0.724	0.547	0.828
3	1062.000	1068.500	6.500	6.473	75.083	2.450	0.196	5.006	0.270	0.320	0.110	0.137	0.666	80.496	0.939
4	1068.500	1082.200	13.700	13.644	47.015	2.386	0.172	3.944	0.127	0.320	0.131	0.137	0.872	0.185	0.839
5	1082.200	1100.900	18.700	18.623	88.351	2.528	0.180	6.818	0.347	0.320	0.069	0.137	0.557	7.699	0.973
6	1100.900	1106.100	5.200	5.179	48.165	2.348	0.175	5.451	0.128	0.320	0.134	0.137	0.720	0.062	0.499
7	1106.100	1126.900	20.800	20.714	75.651	2.460	0.180	6.159	0.273	0.320	0.093	0.137	0.654	398.123	0.950
8	1126.900	1130.000	3.100	3.087	34.829	2.292	0.188	3.283	0.072	0.320	0.165	0.137	0.892	0.105	0.784
9	1130.000	1153.300	23.300	23.204	53.220	2.393	0.183	3.930	0.156	0.320	0.133	0.137	0.839	1.157	0.946
10	1153.300	1153.400	0.100	0.100	64.790	2.405	0.160	5.430	0.206	0.320	0.094	0.137	0.722	0.493	1.000

MKP14

layer	top (MD	Bottom (MD)	Thickness	Thickness (TVD)	average GR	average Density	average Neutron	average resistivity	Vshale	shale porosity	effective porosity	Water resistance (self)	Sw (self)	Rw NAM	Sw NAM
1	792.023	794.461	2.438	2.282	59.058	2.295	0.214	20.439	0.232	0.320	0.140	0.137	0.474	0.049	0.252
2	794.461	794.614	0.153	0.143	52.380	2.210	0.220	42.350	0.188	0.320	0.160	0.137	0.264	0.018	0.100
3	794.614	803.453	8.839	8.275	68.144	2.236	0.304	23.213	0.298	0.320	0.208	0.137	0.264	0.048	0.153
4			0.000	0.000											
5	803.453	808.634	5.181	4.850	85.503	2.201	0.341	10.243	0.456	0.320	0.196	0.137	0.314	0.825	0.684
6	808.634	809.092	0.458	0.429	64.897	2.223	0.217	8.683	0.273	0.320	0.129	0.137	0.465	12860.450	0.500
7	809.092	814.273	5.181	4.850	85.326	2.331	0.278	7.974	0.451	0.320	0.132	0.137	0.397	0.549	0.791
8			0.000	0.000											
9	814.273	814.883	0.610	0.571	57.152	2.216	0.234	10.494	0.220	0.320	0.165	0.137	0.408	0.022	0.200
10			0.000	0.000											

MKP13

layer	top (MD	Bottom (MD)	Thickness	Thickness (TVD)	average GR	average Density	average Neutron	average resistivity	Vshale	shale porosity	effective porosity	Water resistance (self)	Sw (self)	Rw NAM	Sw NAM
1	1046.074	1046.378	0.304	0.237	54.905	2.280	0.220	2.750	0.145	0.320	0.174	0.137	0.868	0.201	0.960
2	1046.378	1055.065	8.687	6.773	22.827	2.233	0.254	1.616	0.038	0.320	0.242	0.137	1.000	0.126	0.949
3	1055.065	1056.132	1.067	0.832	57.696	2.310	0.240	3.010	0.157	0.320	0.190	0.137	0.808	0.338	1.000
4	1056.132	1064.666	8.534	6.654	22.326	2.208	0.261	1.514	0.036	0.320	0.249	0.137	1.000	0.138	1.000
5	1064.666	1065.581	0.915	0.713	74.105	2.408	0.258	4.373	0.225	0.320	0.186	0.137	0.587	1.170	1.000
6	1065.581	1078.230	12.649	9.862	34.706	2.248	0.261	1.737	0.076	0.320	0.237	0.137	0.962	0.171	1.000
7	1078.230	1096.366	18.136	14.140	66.769	2.369	0.276	4.294	0.201	0.320	0.211	0.137	0.621	983.250	0.998
8	1096.366	1100.023	3.657	2.851	29.908	2.176	0.287	1.485	0.059	0.320	0.268	0.137	0.948	0.116	0.852
9	1100.023	1104.900	4.877	3.802	57.045	2.356	0.248	3.468	0.160	0.320	0.197	0.137	0.726	0.931	0.887
10			0.000	0.000											

MKP12A

layer	top (MD	Bottom (MD)	Thickness	Thickness (TVD)	average GR	average Density	average Neutron	average resistivity	Vshale	shale porosity	effective porosity	Water resistance (self)	Sw (self)	Rw NAM	Sw NAM
1	792.500	794.300	1.800	1.736	47.083	2.333	0.226	28.427	0.129	0.320	0.182	0.137	0.300	0.064	0.198
2	794.300	805.300	11.000	10.608	26.270	2.230	0.246	145.564	0.044	0.320	0.227	0.137	0.147	0.041	0.080
3	805.300	806.800	1.500	1.446	46.597	2.260	0.262	111.726	0.132	0.320	0.220	0.137	0.179	0.080	0.125
4	806.800	818.400	11.600	11.186	29.893	2.239	0.245	101.060	0.059	0.320	0.226	0.137	0.174	0.036	0.088
5	818.400	821.200	2.800	2.700	100.560	2.437	0.232	15.181	0.488	0.320	0.084	0.137	0.666	67.887	0.559
6	821.200	821.900	0.700	0.675	73.184	2.370	0.224	17.610	0.261	0.320	0.141	0.137	0.424	0.036	0.220
7	821.900	827.400	5.500	5.304	114.349	2.442	0.269	11.004	0.573	0.320	0.087	0.137	0.667	25.727	0.915
8	827.400	832.600	5.200	5.014	26.951	2.180	0.266	62.843	0.046	0.320	0.251	0.137	0.176	0.153	0.097
9	832.600	844.000	11.400	10.993	47.897	2.248	0.260	31.129	0.143	0.320	0.214	0.137	0.295	105.141	0.289
10	844.000	844.400	0.400	0.386	84.648	2.360	0.258	10.162	0.344	0.320	0.148	0.137	0.538	0.012	0.176

MKP12

layer	top (MD	Bottom (MD)	Thickness	Thickness (TVD)	average GR	average Density	average Neutron	average resistivity	Vshale	shale porosity	effective porosity	Water resistance (self)	Sw (self)	Rw NAM	Sw NAM
1	923.087	923.392	0.305	0.298	56.535	2.405	0.205	2.920	0.208	0.320	0.138	0.137	0.621	0.654	1.000
2	923.392	941.832	18.440	17.995	24.342	2.189	0.280	0.850	0.042	0.320	0.267	0.137	1.000	0.073	0.904
3	941.832	967.283	25.451	24.836	72.063	2.430	0.226	3.773	0.325	0.320	0.125	0.137	0.496	46.958	0.936
4	967.283	980.999	13.716	13.385	21.810	2.196	0.266	0.778	0.031	0.320	0.256	0.137	1.000	0.074	1.000
5	980.999	988.314	7.315	7.138	71.213	2.417	0.248	4.175	0.332	0.320	0.142	0.137	0.562	0.404	1.000
6	988.314	993.800	5.486	5.353	28.767	2.201	0.282	0.951	0.063	0.320	0.262	0.137	1.000	0.603	1.000
7	993.800	999.592	5.792	5.652	85.751	2.473	0.240	4.189	0.431	0.320	0.102	0.137	0.387	38834.361	1.000
8	999.592	1014.374	14.782	14.425	31.398	2.206	0.287	0.819	0.082	0.320	0.261	0.137	1.000	0.483	1.000
9	1014.374	1026.109	11.735	11.452	41.329	2.290	0.270	1.489	0.133	0.320	0.228	0.137	0.963	2.855	1.000
10	1026.109	1026.567	0.458	0.447	75.103	2.337	0.270	2.397	0.342	0.320	0.160	0.137	0.494	2.582	1.000

MKP11

layer	top (MD	Bottom (MD)	Thickness	Thickness (TVD)	average GR	average Density	average Neutron	average resistivity	Vshale	shale porosity	effective porosity	Water resistance (self)	Sw (self)	Rw NAM	Sw NAM
1	857.098	858.774	1.676	1.245	58.886	2.363	0.226	15.027	0.219	0.320	0.156	0.137	0.364	170.758	0.865
2	858.774	874.471	15.697	11.661	28.305	2.198	0.256	100.627	0.048	0.320	0.240	0.137	0.154	6.974	0.164
3	874.471	876.605	2.134	1.585	50.711	2.231	0.279	19.404	0.165	0.320	0.226	0.137	0.261	0.045	0.161
4	876.605	885.901	9.296	6.906	28.899	2.195	0.267	42.776	0.050	0.320	0.251	0.137	0.202	0.121	0.123
5	885.901	891.083	5.182	3.849	81.127	2.395	0.278	8.762	0.391	0.320	0.153	0.137	0.384	10.643	0.862
6	891.083	893.064	1.981	1.472	63.090	2.408	0.198	14.315	0.244	0.320	0.120	0.137	0.414	21.998	0.695
7	893.064	895.045	1.981	1.472	72.973	2.355	0.257	11.564	0.330	0.320	0.151	0.137	0.362	40.238	0.822
8	895.045	898.550	3.505	2.604	35.012	2.196	0.270	35.075	0.079	0.320	0.245	0.137	0.220	0.375	0.160
9	898.550	908.152	9.602	7.133	55.663	2.328	0.246	13.645	0.199	0.320	0.182	0.137	0.349	24.177	0.458
10	908.152	909.523	1.371	1.018	95.480	2.407	0.282	6.969	0.534	0.320	0.111	0.137	0.411	24.320	0.921

MKP10

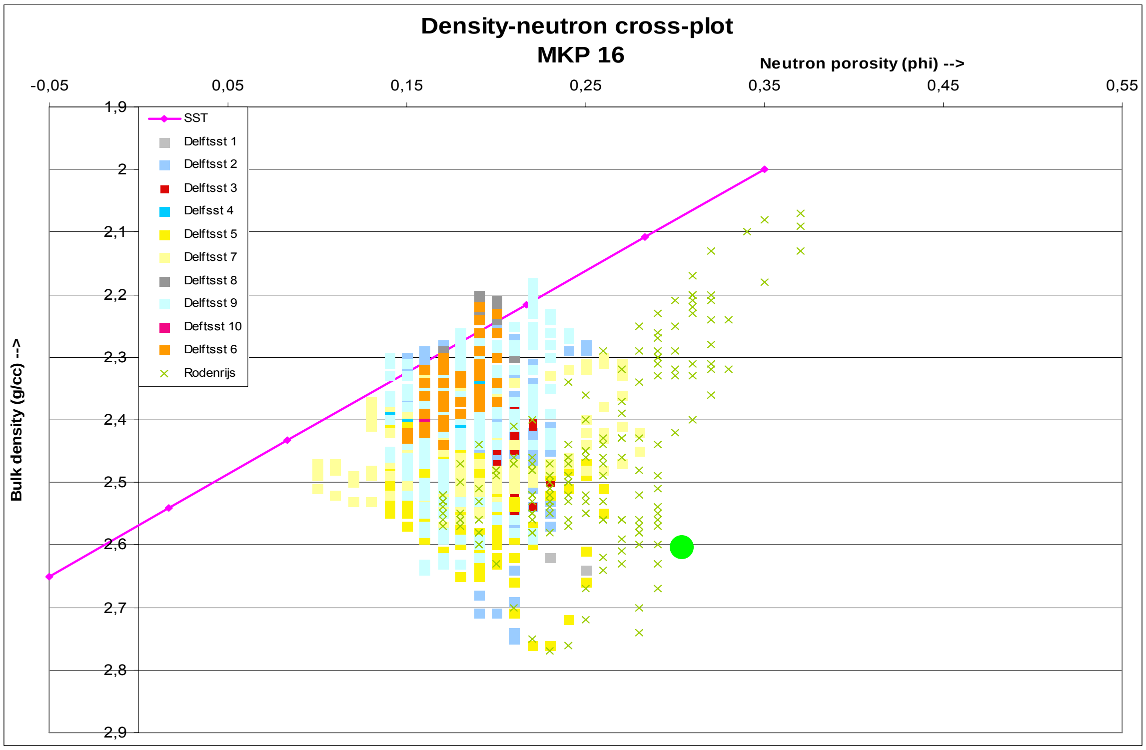
layer	top (MD	Bottom (MD)	Thickness	Thickness (TVD)	average GR	average Density	average Neutron	average resistivity	Vshale	shale porosity	effective porosity	Water resistance (self)	Sw (self)	Rw NAM	Sw NAM
1	659.587	665.531	5.944	4.832	36.506	2.205	0.245	106.074	0.109	0.320	0.210	0.137	0.089	0.029	0.062
2	665.531	677.723	12.192	9.911	30.453	2.197	0.229	167.290	0.070	0.320	0.207	0.137	0.083	0.022	0.045
3	677.723	679.094	1.371	1.114	52.980	2.101	0.258	27.652	0.236	0.320	0.182	0.137	0.117	0.894	1.000
4	679.094	705.002	25.908	21.060	29.756	2.200	0.229	172.628	0.067	0.320	0.208	0.137	0.101	0.028	0.059
5	705.002	706.984	1.982	1.611	75.637	2.300	0.218	8.565	0.462	0.320	0.071	0.137	0.143	0.008	0.650
6			0.000	0.000											
7	706.984	710.336	3.352	2.725	71.959	2.350	0.230	7.761	0.427	0.320	0.093	0.137	0.154	0.041	0.839
8	710.336	716.890	6.554	5.328	27.950	2.206	0.233	53.919	0.062	0.320	0.223	0.137	0.139	0.030	0.085
9	716.890	719.785	2.895	2.353	50.835	2.261	0.223	18.670	0.213	0.320	0.155	0.137	0.147	0.055	0.172
10	719.785	721.157	1.372	1.115	72.799	2.321	0.226	7.723	0.429	0.320	0.088	0.137	0.146	0.037	1.000

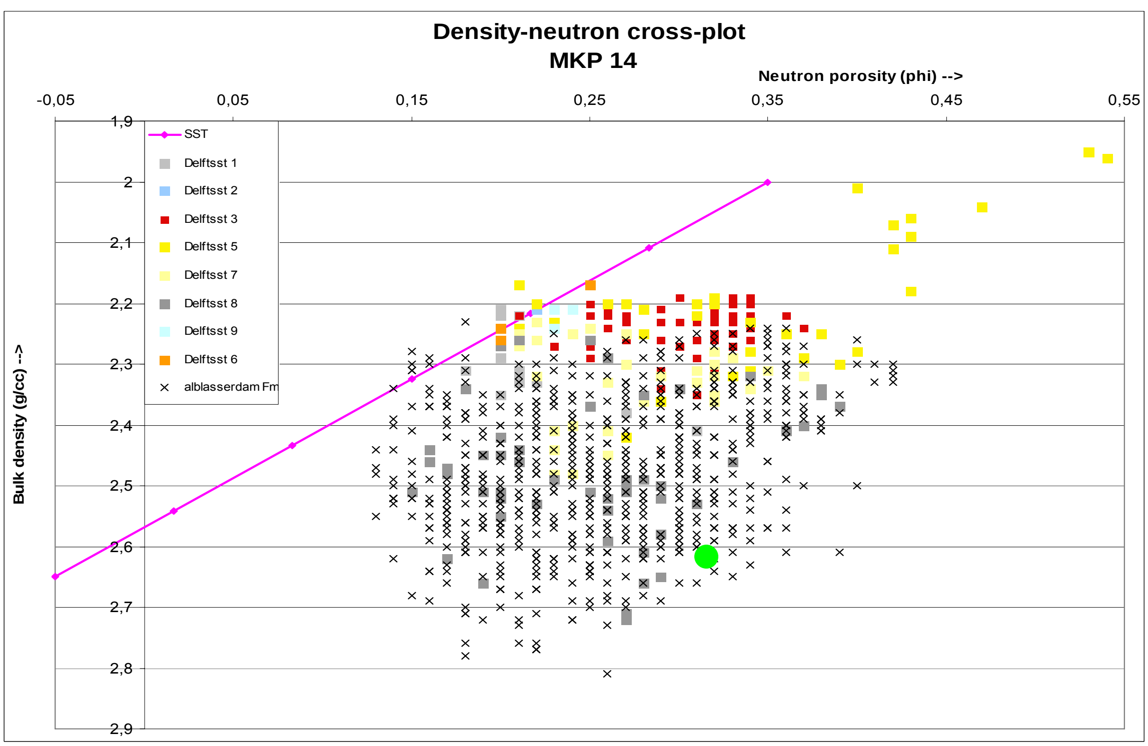
MKP 9A

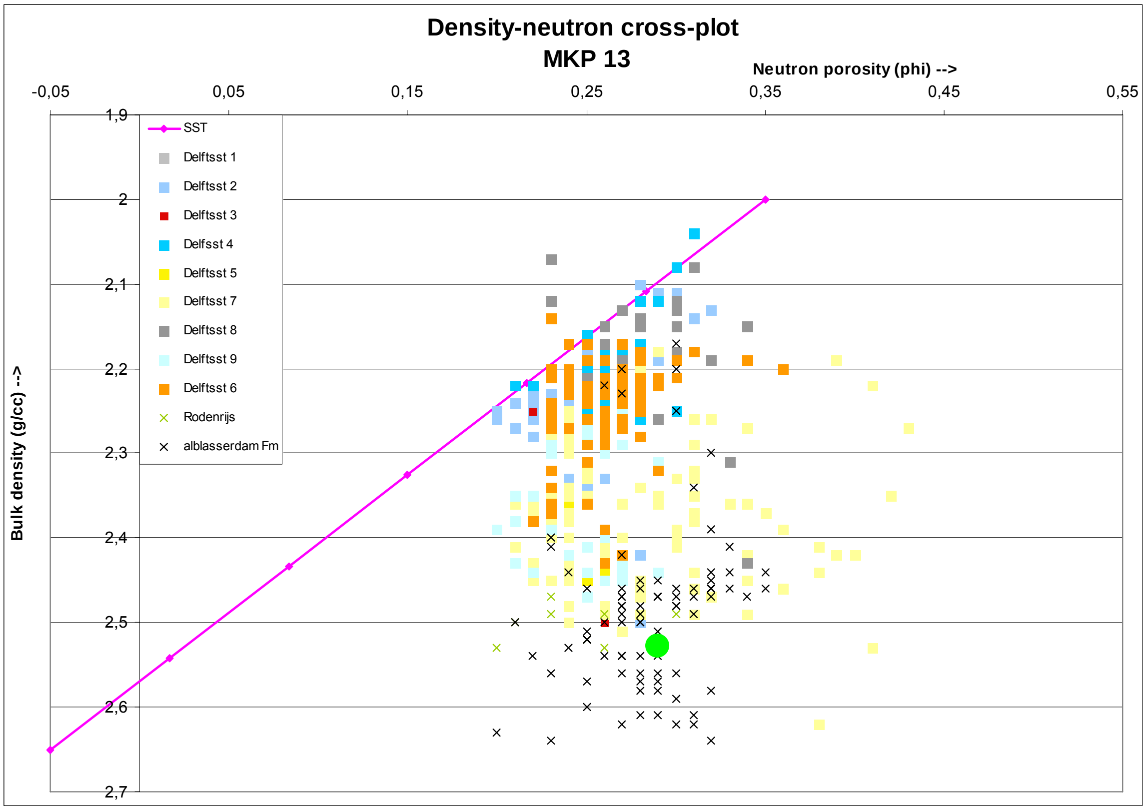
layer	top (MD	Bottom (MD)	Thickness	Thickness (TVD)	average GR	average Density	average Neutron	average resistivity	Vshale	shale porosity	Water resistance (self)
1	850.087	853.592	3.505	3.015	25.554	2.266		48.911	0.046	0.320	0.137
2	853.592	859.688	6.096	5.244	18.804	2.263		67.060	0.024	0.320	0.137
3	859.688	862.889	3.201	2.754	63.689	2.438		9.262	0.190	0.320	0.137
4	862.889	869.442	6.553	5.637	20.785	2.242		33.018	0.030	0.320	0.137
5	869.442	874.471	5.029	4.326	68.374	2.502		6.885	0.213	0.320	0.137
6	874.471	878.129	3.658	3.147	34.729	2.337		14.541	0.079	0.320	0.137
7	878.129	883.768	5.639	4.851	67.125	2.492		10.594	0.206	0.320	0.137
8	883.768	893.674	9.906	8.521	18.167	2.240		5.589	0.022	0.320	0.137
9	893.674	896.569	2.895	2.490	42.876	2.371		2.664	0.104	0.320	0.137
10			0.000	0.000							

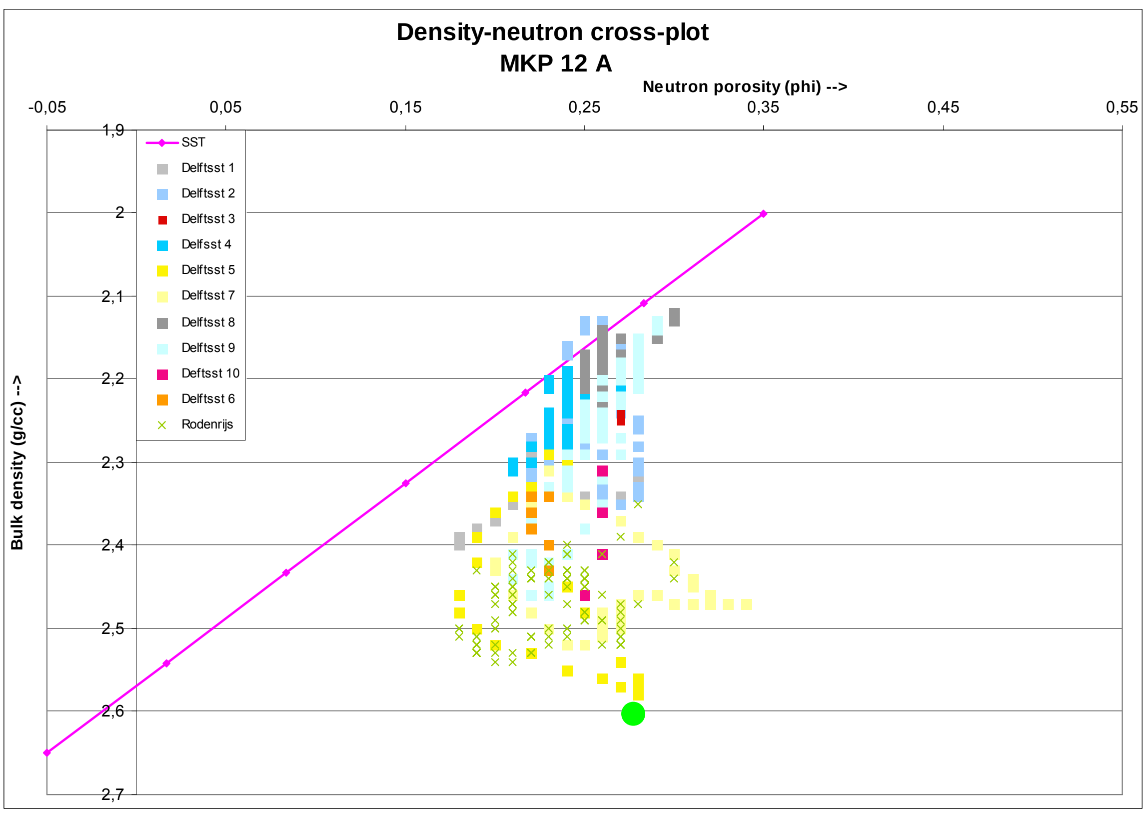
Appendix E

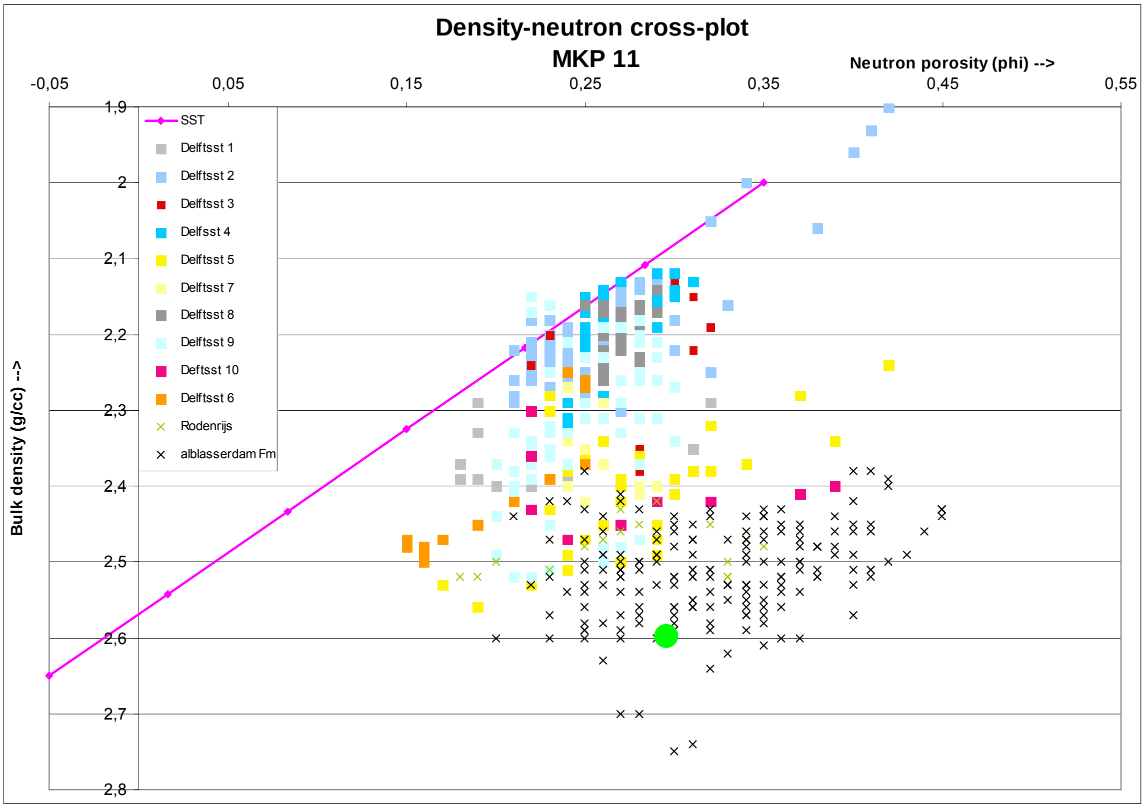
In appendix D are the FDC-CNL plots given of MKP 16, MKP 14, MKP 13, MKP 12A, MKP 11 and MKP 10.
The green dot displays the shale point.

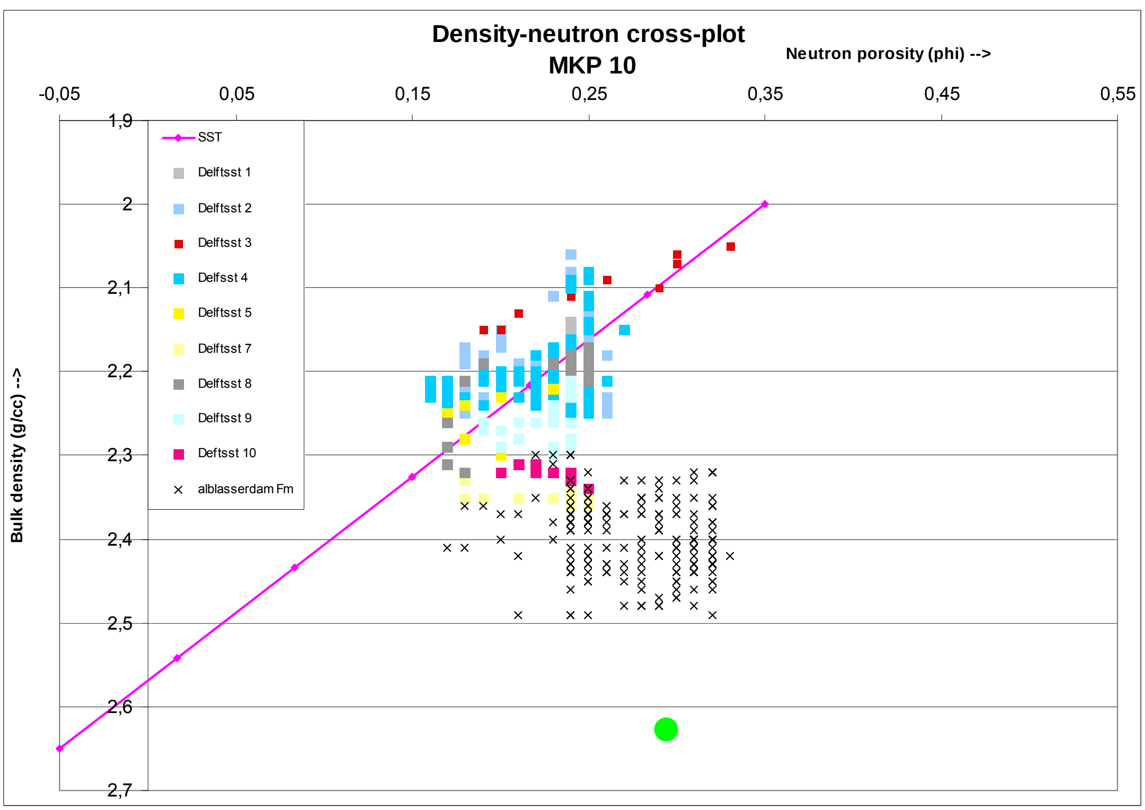





Density-neutron cross-plot
MKP 13
Neutron porosity (phi) -->
Bulk density (g/cc) -->
-0,05
0,05
0,15
0,25
0,35
0,45
0,55
1,9
2
2,1
2,2
2,3
2,4
2,5
2,6
2,7
SST
Delftsst 1
Delftsst 2
Delftsst 3
Delftsst 4
Delftsst 5
Delftsst 7
Delftsst 8
Delftsst 9
Delftsst 6
Rodenrijs
alblasserdam Fm

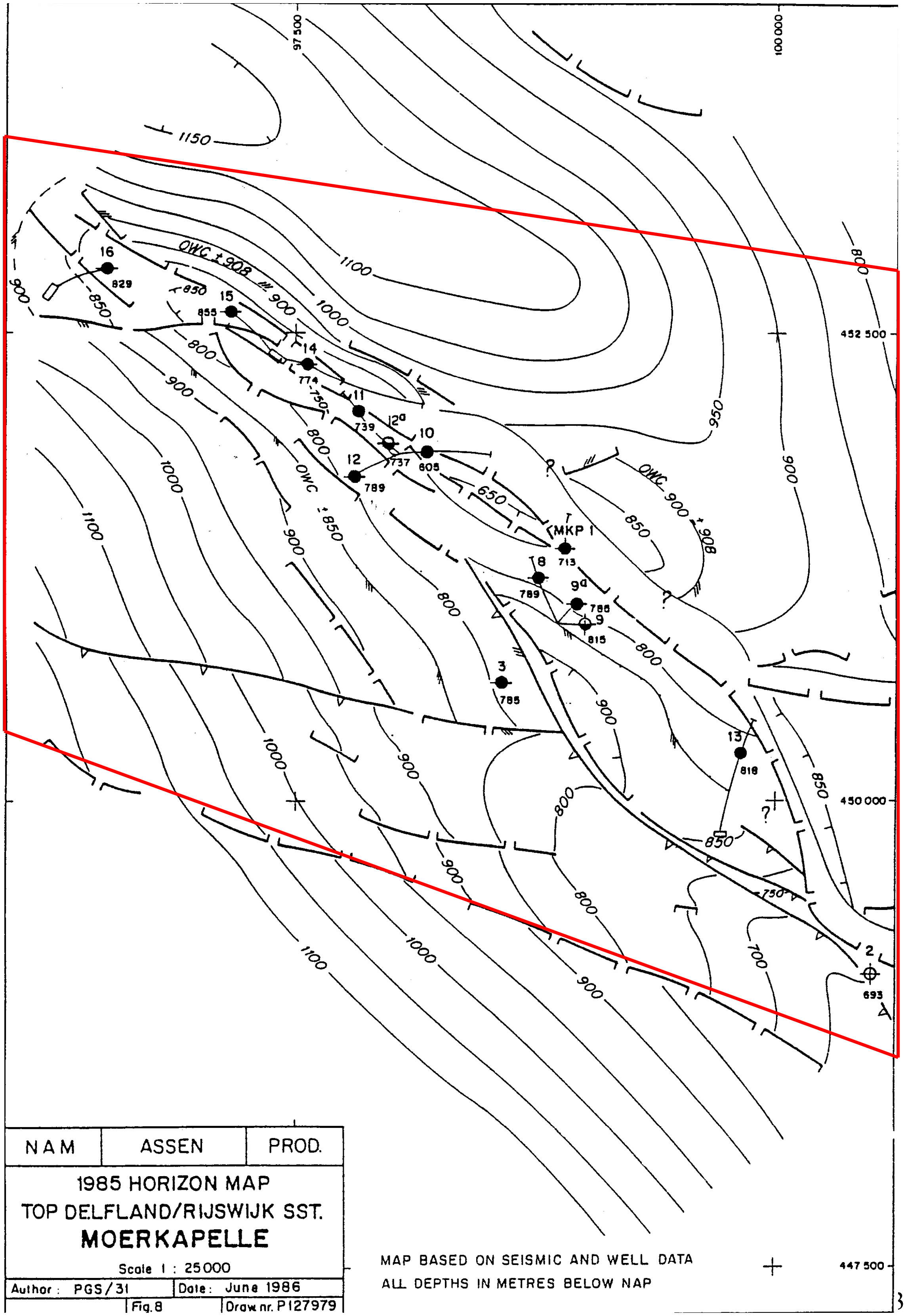

Density-neutron cross-plot
MKP 12 A
Neutron porosity (phi) -->
Bulk density (g/cc) -->
-0,05
0,05
0,15
0,25
0,35
0,45
0,55
1,9
2
2,1
2,2
2,3
2,4
2,5
2,6
2,7
SST
Delftsst 1
Delftsst 2
Delftsst 3
Delfsst 4
Delftsst 5
Delftsst 7
Delftsst 8
Delftsst 9
Deftsst 10
Delftsst 6
Rodenrijs


Density-neutron cross-plot
MKP 11
Neutron porosity (phi) -->
-0,05
0,05
0,15
0,25
0,35
0,45
0,55
1,9
2
2,1
2,2
2,3
2,4
2,5
2,6
2,7
2,8
Bulk density (g/cc) -->
SST
Delftsst 1
Delftsst 2
Delftsst 3
Delfsst 4
Delftsst 5
Delftsst 7
Delftsst 8
Delftsst 9
Deftsst 10
Delftsst 6
Rodenrijs
alblasserdam Fm


Density-neutron cross-plot
MKP 10
Neutron porosity (phi) -->
-0,05
0,05
0,15
0,25
0,35
0,45
0,55
1,9
2
2,1
2,2
2,3
2,4
2,5
2,6
2,7
Bulk density (g/cc) -->
SST
Delftsst 1
Delftsst 2
Delftsst 3
Delfsst 4
Delftsst 5
Delftsst 7
Delftsst 8
Delftsst 9
Deftsst 10
alblasserdam Fm

Appendic F

The surface map of the Moerkapelle Field, including the MKPs, is given in this appendix The concession is inside the red quadrangle.



Appendix G

The flow chart of this Bachelor project