DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2007/85

Special core analysis for Hess Denmark Well: Rigs-3

Electrical properties and permeability at overburden stress conditions

Niels Springer

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

G E U S

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Contents

Enclosure: - Data on CD-ROM

Req. no.: 09201-566
File: Rigs-3_SCALrep.doc
Rigs-3_images.doc
Rigs-3_electrical.xls

1. Introduction

At the request of Hess Denmark ApS, GEUS Core Laboratory has performed special core analysis on samples from the Rigs-3 well, the South Arne Field, Danish North Sea.

The experimental programme was specified in e-mail communications with Mr. Søren Christensen during June 2007. The following analytical programme was finally agreed on:

- Screening of plugs for SCAL
- Standard core analysis on plugs for SCAL
- Determination of insoluble residue
- Liquid permeability at overburden conditions
- Electrical properties at overburden conditions

Preliminary data have been reported to Hess DK by e-mail comm. during the period July 2007 to December 2007.

2 Sampling and analytical procedures

The electrical survey conducted on 5 plug samples from Rigs-3 is a follow-up on the large resistivity study carried out on the South Arne Field in 2005 by the laboratory. The equipment and techniques are essentially the same as used in the former study. [1]

2.1 Plug quality screening

Based on routine core analysis data 10 plugs of 38 mm diameter were X-ray CT-screened at the scanning facility at Department of Chemical Engineering, the Technical University of Denmark, table 2.1. Two longitudinal cuts perpendicular to each other are recorded for each plug. Scanning images and details of the instrumental settings are given in chapter 7.

2.2 Preparation

From inspection of the scanning images 5 apparently homogeneous plugs having a fair range in porosity were selected for the electrical measurements. All plugs had previously been Soxhlet cleaned during the conventional core analysis study but went through an additional cold flush cleaning with methanol and toluene before special core analysis (SCAL) test. The plugs were then dried at 110 °C and analyzed for routine poro-perm, table 5.1. A determination of the insoluble residue (ISR) was included with the experimental programme, but plug trims were not at hand; therefore a copy set of 38 mm diameter plugs were drilled close to the original plugs, cleaned and analyzed for ISR and pct. quartz, table 5.2.

2.3 Electrical properties and liquid permeability

Samples were vacuum and pressure saturated in simulated formation brine for a week, table 2.2, and left to equilibrate in brine under a slight vacuum in an anaerobic jar for another week before electrical measurement commenced.The samples were then installed in single resistivity cells and a hydrostatic confining pressure of 145 psi [1 MPa] was applied. Approx. 2-3 PV's of fresh brine was flushed through the samples to displace air from the core holder. Pressure was then increased to 1200 psi [8.2 MPa] hydrostatic conf. P and the sample left to settle until the next day. The amount of liquid expelled was used to calculate the porosity reduction. Liquid flow was then started and when stable conditions was observed, consequtive readings of flowrate and differential pressure were recorded. Liquid flow was now stopped and during the next week a number of resistivity readings were taken to determine the formation resistivity factor FRF.

The resistivity index RI was measured by a technique developed for low permeability samples, published by Korsbech et al.[2] Samples were flushed with a 2.5 times diluted formation brine, table 2.3, the pressure on the core holders relieved and the samples left to settle in a jar under a slight vacuum for 2 months in the diluted brine. Samples were then removed from the vacuum jar and left to evaporate under laboratory conditions until a precalculated weight had been reached and the original brine concentration re-established. The samples were now at 40% water saturation and ready to be measured for the resistivity index RI at overburden conditions. The resistivity was measured with the samples mounted in single resistivity cells during a period of one week until stable readings were obtained.

Data for ‘RI’ and 'FRF' as well as Archie parameters 'm' and ‘n’ are presented in section 5.

Table 2.1. Rigs-3 resistivity study; list of former routine core analysis plugs received for screening. Samples selected for resistivity measurement after CT-screening are indicated (x). Only samples from the Tor Formation have been included with the study.

Well	Formation	Plug #	Depth MD	Selected	Comments
Rigs-3	Tor	13	3035.10	x	
	Tor	25	3039.13		
	Tor	32	3041.45		
	Tor	39	3043.77	x	
	Tor	41	3044.51	x	
	Tor	42	3044.75		
	Tor	46	3046.16		
	Tor	61	3051.30		
	Tor	74	3055.45	x	
	Tor	82	3058.15	x	

Table 2.2. South Arne simulated formation water analysis. Measured physical properties appear below.

Subject brine: Syd Arne formation brine

Element	Concentration	Compound	Gram compound per		
	mg/L		1 liter	3 liter	5 liter
Na total	32930				
Na+	32930	NaCl	83.707	251.122	418.54
Na+	0	NaHCO3	0.000	0.000	0.00
K+	522	KCl	0.995	2.986	4.98
Mg2+	665	MgCl2, 6H2O	5.561	16.683	27.81
Ca2+		CaCl2	0.000	0.000	0.00
Ca2+	5667	CaCl2, 2H2O	20.787	62.362	103.94
Sr2+	0	SrCl2, 6H2O	0.000	0.000	0.00
Ba2+		BaCl2, 2H2O	0.000	0.000	0.000
Cl-	63220				
HCO3-	0.0				

TDS:	**103004**	**mg/L**	~1.763	mol/L NaCl eqv.
pH:		**@ 23 C**		

Comments: Slightly modified compared to the brine used in the 2005 study

Physical data:	**Resistivity Rw :**	**0.075**	**ohmm @ 25.0 ºC**
	Calculated Rw :	**0.074**	**ohmm @ 25.0 ºC**
	Density dw :	**1.068**	**g/cc @ 25.0 ºC**
	Calculated dw :	**1.066**	**g/cc @ 25.0 ºC**
	Viscosity:	**1.093**	**cP @ 25 ºC**

Table 2.3. South Arne simulated formation water analysis diluted 2.5 times to allow a final water saturation of 40% in the resistivity index study. Measured physical properties appear below.

Subject brine: Syd Arne brine 40%

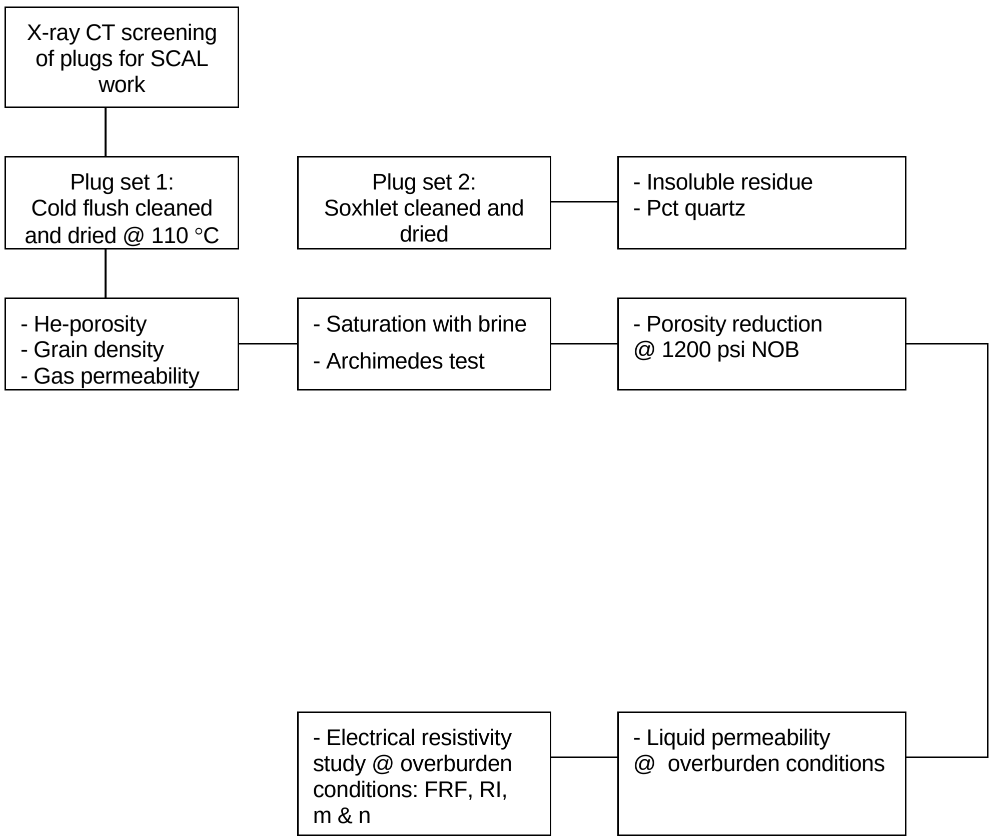
Element	Concentration	Compound	Gram compound per		
	mg/L		1 liter	3 liter	5 liter
Na total	13172				
Na+	13172	NaCl	33.483	100.449	167.41
Na+	0	NaHCO3	0.000	0.000	0.00
K+	209	KCl	0.398	1.195	1.99
Mg2+	266	MgCl2, 6H2O	2.224	6.673	11.12
Ca2+		CaCl2	0.000	0.000	0.00
Ca2+	2267	CaCl2, 2H2O	8.316	24.947	41.58
Sr2+	0	SrCl2, 6H2O	0.000	0.000	0.00
Ba2+		BaCl2, 2H2O	0.000	0.000	0.000
Cl-	25288				
HCO3-	0.0				

TDS:	**41202**	**mg/L**	~	0.705	mol/L NaCl eqv.
pH:		**@ 23 C**			

Comments: Slightly modified from original SA brine, and diluted 2.5 times

Physical data:			
	Resistivity Rw :	**0.159**	**ohmm @ 25.0 ºC**
	Calculated Rw :	**0.158**	**ohmm @ 25.0 ºC**
	Density dw :	**1.026**	**g/cc @ 25.0 ºC**
	Calculated dw :	**1.025**	**g/cc @ 25.0 ºC**
	Viscosity:		**cP @ 25 ºC**

3 Flow diagram of the analytical procedures



4 Analytical Methods

Electrical measurements are performed at 25 ± ½ ºC, and to the guidelines established by the Society of Core Analysts [4]. A temperature log may be provided on request and included with the attached CD-ROM.

4.1 Insoluble residue and amount of quartz in the residue

The sample is crushed and dried, and calcite is removed by using a buffered acetic acid at pH 4.5. This mild dissolution of the calcite is carried out in order to avoid dissolution of non – calcite minerals. The amount of insoluble residue is given as a weight percent rel. to the original dry sample weight.

X – ray diffraction (XRD) is carried out on randomly oriented specimens using a Philips 1050 goniometer with Co - $K\alpha$ radiation (pulse – high selection and Fe – filter). The amount of quartz in the residue is determined using quartz 4.5 - 45 µm in size as a standard. The result is given as a weight percent rel. to the insoluble residue.

4.2 Overburden measurements

The following field data were supplied by Amerada Hess DK:

Gross overburden pressure:	8260 psi
Reservoir pressure:	6260 psi
Net confining pressure:	2000 psi

which translates to a hydrostatic confing pressure of ~1200 psi in the electrical properties study.

Porosity: The initial porosity is determined at room conditions. Archimedes test is applied to the fully saturated plug sample, and in combination with the sample grain density the porosity is calculated. During testing the sample pore volume decreases as overburden increases. This is observed as an amount of liquid expelled from the sample into a graduated tube, or constantly monitored using an electronic Mettler balance connected to a PC. The final reading is taken after a fixed time or when a stable level has been reached on the balance. The porosity reduction is calculated as the relative decrease in the initial porosity:

$$Ø_i = \frac{V_{pi}}{V_{bi}}$$

$$Ø_{i+\Delta p} = \frac{V_{pi} - \Delta V_p}{V_{bi} - \Delta V_p}$$

The porosity reduction is then given as:

$$\frac{Ø_{i+\Delta p}}{Ø_i} \cdot 100\,\% = \frac{V_{pi} - \Delta V_p}{V_{bi} - \Delta V_p} \cdot \frac{V_{bi}}{V_{pi}} \cdot 100\,\%$$

Where $Ø_i$ = initial porosity
V_{pi} = initial pore volume
V_{bi} = initial bulk volume
$Ø_{i+\Delta P}$ = new porosity induced by a certain change Δp in confining stress.
ΔV_p = change in pore volume due to the change in confining stress.

The initial change in the pore volume that occurs from room conditions to the lowest confining stress applied in the study is extrapolated from a liquid production curve (produced liquid vs effective confining stress).

4.3 Formation resistivity factor

In a “clean” formation (non-shaly) the formation factor F is described by Archie’s equation:

$$F = \frac{R_0}{R_w} = \frac{a}{Ø^m}$$

Where

R_0 = resistivity of sample @ S_w = 100%
R_w = resistivity of formation brine
Ø = porosity
a = constant
m = cementation exponent

For a plug sample F is calculated from the following formula:

$$F = \frac{1}{R_w} \cdot \frac{z \cdot A}{L}$$

Where

R_w = resistivity of brine in ohm-m
z = impedance of plug sample in ohm @ S_w = 100%
A = area of the plug in m^2
L = length of plug in m

Rearranging Archie’s equation for the formation factor:

$$\log F = -m \log Ø + \log a$$

produces a straight-line relationship in a double logarithmic diagram where F is plotted as a function of Ø. The constant 'a' is then determined as the intercept and the cementation exponent 'm' as the slope of the best fit straight line. Values for 'm' are usually preferred for a = 1, which is expected from theoretical grounds. Therefore a set of regression constants are given for a regression line which has been biased through (1,1).

The measurement of F is performed with the plug mounted in a 2-electrode resistivity core holder at an overburden pressure >300 psi. The plug is allowed to settle for more that 3 hours. The porosity reduction/pore volume compressibility is recorded consecutively. The plug resistance is measured as the impedance to an AC signal of 5-20 kHz frequency depending on rock properties (minimum phase angle). Data logging is performed using the HP 4276A LCZ-meter controlled by a PC. The resistivity of the brine is measured in a conductivity meter (Radiometer Analytical CDM 210). The measured formation brine resistivity is checked against a model calculated resistivity.

4.4 Resistivity index

In a “clean” formation (non-shaly) Archie determined experimentally that the water saturation could be expressed by the following equation:

$$S_w{}^n = \frac{FR_w}{R_t} = \frac{R_o}{R_t} = \frac{1}{RI}, \qquad RI = \frac{R_t}{R_o}$$

where S_w = water saturation
n = saturation exponent
F = formation resistivity factor
RI = resistivity index
R_0 = resistivity of sample @ S_w = 100% in ohm-m
R_t = resistivity of sample @ S_w < 100% in ohm-m
R_w = resistivity of brine in ohm-m

Rearranging Archie’s equation for the water saturation :

$$RI = S_w{}^{-n}$$

and $$\log(RI) = -n \ \log(S_w)$$

In a double logarithmic diagram consecutive values of S_w and RI shall produce a straight line from which the saturation exponent 'n' can be determined as the slope.

The measurement of RI is performed with the plug mounted in a resistivity core holder at an overburden pressure >300 psi. The plug is allowed to settle for more that 3 hours. The porosity reduction/pore volume compressibility can not normally be measured but is estimated from other sources, preferebly an overburden experiment. The two-electrode method is normally applied and the resistance measured as the impedance to an AC signal of 5-20 kHz frequency depending of the resistivity cell design and the type of rock (minimum phase angle). Data logging is performed using the HP 4276A LCZ-meter controlled by a PC.

Drainage of the sample may be carried out using a porous plate, and therefore the measurement of RI is conveniently combined with air/brine or oil/brine capillary pressure experiments. For low permeability material this may take very long time and often uneven saturation profiles are generated in the samples that will affect the resistivity measurement. For such low permeability samples a different desaturation technique may be applied [2]. A diluted formation brine is used and the samples allowed to evaporate under room conditions to a precalculated weight whereby a specific water saturation is obtained and the original brine concentration regenerated. A homogeneous brine distribution is normally obtained within a week due to diffusion and capillary forces. The non-wetting phase is air.

5 Results

Nomenclature

L	– sample length	[cm]	F or FRF	– formation resistivity factor
D	– sample diameter	[cm]	F*	- intrinsic formation factor
A	- sample area	[cm^2]	RI	– resistivity index
BV	– bulk volume	[cc]	m	– cementation exponent
PV	– pore volume	[cc]	m*	- intrinsic porosity exponent
Δ PV	– pore volume change	[ml]	n	– saturation exponent
GD	– grain density	[g/cc]	a	– Archie constant, or a dimensional correction factor in compressibility calculations
V	– volume	[ml]	R_o	- resistivity of water saturated sample [Ω m]
Δ V	– volume change	[ml]	R_w	- resistivity of formation water [Ωm]
Ø	– porosity	[pct or frc]	C_o	- core conductivity [S/m]
S_w	- water saturation	[pct or frc]	C_w	- formation water conductivity [S/m]
S_{wf}	- final water saturation	[pct or frc]	Z_o	- impedance of water saturated sample [Ω]
$_i$	- Subscript for "initial"		Z_t	- impedance of sample at $S_w < 1$ [Ω]
imp	- impedance	[ohm]	nd/na	- not determined/analyzed
τ	- tortuosity		WW_{calc}	- wet weight calculated from plug volume and core analysis data [g]
			WW_{meas}	- wet weight measured [g]

5.1 Conventional core analysis and insoluble residue

Table 5.1 below lists the routine core analysis data measured before the SCAL test. The He-porosity figure from table 5.1 is not always used directly in the following SCAL test; the initial porosity figure may be a mean value between the He-porosity and an Archimedes porosity that is routinely measured on saturated plugs before the SCAL test is initiated.

Table 5.1. Rigs-3 resistivity study; conventional core analysis data measured after additional cold flush, miscible liquids cleaning of plugs selected for the electrical study. Gas permeability was measured @ 400 psi confining sleeve pressure.

Sample ID	Depth [m]	Plug type	Gas Perm [mD]	Klink.Perm [mD]	Klink.Corr Coef.	Por [%]	Grain Dens [g/ccm]
13	3035.10	Hori	0.226	0.046	0.996	18.2	2.717
39	3043.77	Hori	0.434	0.138	0.999	21.6	2.718
41	3044.51	Hori	0.295	0.069	0.996	19.3	2.718
74	3055.45	Hori	0.581	0.217	0.996	22.7	2.717
82	3058.15	Hori	0.254	0.065	0.993	17.5	2.719

Table 5.2. Rigs-3 resistivity study; insoluble residue (ISR) and quartz content in the insoluble residue in Tor Fm chalk. Dry clean sample material analyzed was 40 – 60 [g] per plug sample.

Plug ID	Depth [m]	ISR [%]	Qz in ISR [%]
13 A	3035,18	3	30
39 A	3043,83	3	20
41 A	3044,57	3	40
74 A	3055,47	1	50
82 A	3058,14	1	50

Analytical data by GEUS Clay Minerals Lab

5.2 Electrical properties

As seen from the scanning images in chapter 7 the Tor Formation plugs appear unusually homogeneous and clay and silica content is low, table 5.2. Measurement of sample resistivity was uncomplicated, and there is no reason to suspect that a fixed regression through (1,1) in a double logaritmic plot is not valid for the samples.

5.2.1 Formation Resistivity Factor

Results are listed in the sheets below; raw data are included with the attached CD-ROM. "Best estimate" regression analysis data are listed in table 5.3.

Table 5.3. Archie's cementation exponent 'm' for the Tor Fm chalk in the Rigs-3 well.

Chalk formation	Archie's 'm' from linear regression
Tor Fm	1.97

Subject: Formation Resistivity Factor data | **Well: Rigs-3**

Company : Hess DK | **GEUS Core Lab, 01.08.2007**

Archie parameters :	a =	1,0	Brine resistivity :	0,075	[ohmm]	@ 25 °C
	m =	1,97	Intrinsic cell impedance:	0,32	[ohm]	
(tortuosity)	τ =	4,9				

Plug no.	Plug porosity data @ 1200 psi			Plug permeability data @ 1200 psi			Plug resistivity data @ 1200 psi		
	Δ PV [cc]	PV [cc]	**Ø [%]**	L [cm]	A [cm^2]	**K_l [mD]**	|Z0| [ohm]	Phase [deg]	**FRF**
13	0,16	9,75	17,95	4,825	11,26	0,04	99,9	0,06	31,02
39	0,15	11,79	21,41	4,896	11,25	0,09	66,1	-0,07	20,20
41	0,24	10,81	19,11	5,027	11,26	0,06	83,2	-0,11	24,78
74	0,19	12,47	22,65	4,866	11,31	0,13	60,8	-0,05	18,79
82	0,14	9,57	17,49	4,828	11,333	0,06	101,2	-0,12	31,58

Well: Rigs-3
GEUS Core Lab, 01.08.2007

Plug and cell impedance measured @ 5, 10 & 20 kHz
(minimum phase angle data only given in the table below)

Plug no.	Imp data @ 1200 psi				Perm data @ 1200 psi		Compressibility data @ 1200 psi		
	Imp1 [ohm]	Imp2 [ohm]	Phase1 [deg]	Phase2 [deg]	Flow rate [ml/h]	Δ P [psi]	BV [cc]	Δ BV [%]	a
13	100,79	99,73	0,06	0,05	2,306	119	54,34	0,29	0,0010
39	66,80	66,05	-0,07	-0,07	2,308	49	55,08	0,27	0,0009
41	83,90	83,13	-0,11	-0,11	2,454	79	56,60	0,42	0,0014
74	61,46	60,77	-0,03	-0,07	2,253	34	55,05	0,34	0,0011
82	101,72	101,25	-0,11	-0,12	2,391	80	54,72	0,26	0,0009

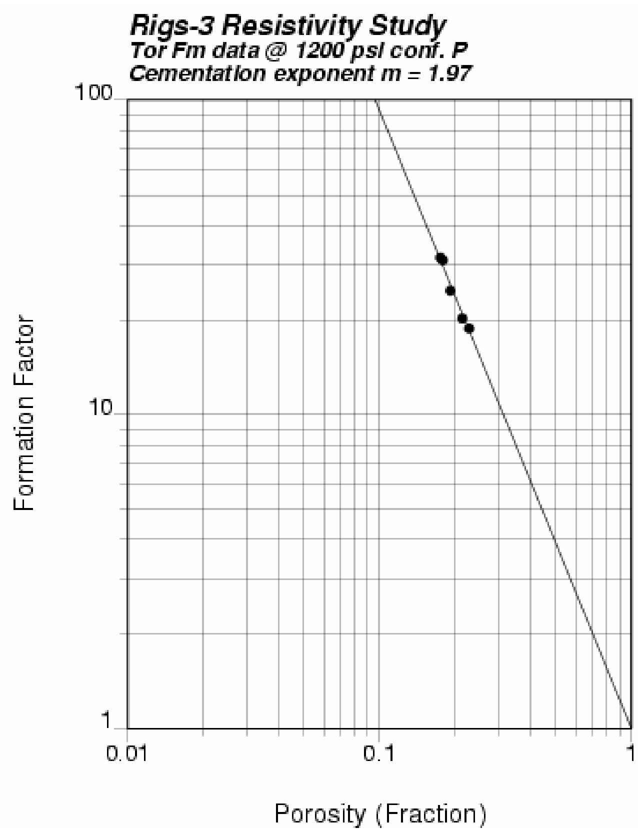
Subject: Formation Resistivity Factor data **Well: Rigs-3**

Company : Hess DK

Overburden FRF data and cementation exponent 'm' **GEUS Core Lab, 01.08.2007**

Reservoir unit: **Tor Fm** **Regression 'm' :** **1,97**

Well	Plug no.	Depth	Overburden data @ 1200 psi confining P				
		[m]	K_l [mD]	Ø [%]	FRF	τ	Archie 'm'
Rigs-3	13	3035,10	0,04	17,95	31,02	5,6	2,00
	39	3043,77	0,09	21,41	20,20	4,3	1,95
	41	3044,51	0,06	19,11	24,78	4,7	1,94
	74	3055,45	0,13	22,65	18,79	4,3	1,98
	82	3058,15	0,06	17,49	31,58	5,5	1,98



Number of data 5
Number plotted 5

X Variable:
geom. mean 0.196
std. dev. 1.105

Y Variable:
geom. mean 24.711
std. dev. 1.238

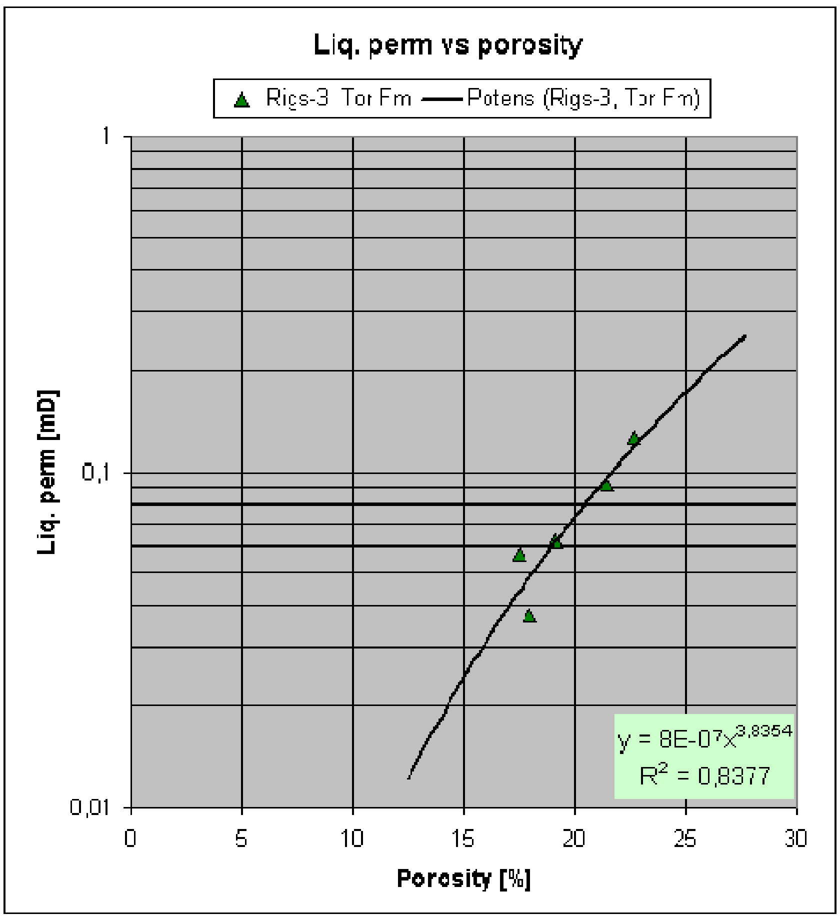
Correlation -0.988
Rank correlation -1.000

Regression:
intercept 1.00
slope -1.97

Subject: Liquid permeability	Well: Rigs-3
Company : Hess DK	
Overburden poro-perm data	GEUS Core Lab, 01.08.2007

Reservoir unit: **Tor Fm**

Well	Plug no.	Depth	Overburden data @ 1200 psi confining P				
		[m]	K_l [mD]	Ø [%]	FRF	τ	Archie 'm'
Rigs-3	13	3035,10	0,04	17,95	31,02	5,6	2,00
	39	3043,77	0,09	21,41	20,20	4,3	1,95
	41	3044,51	0,06	19,11	24,78	4,7	1,94
	74	3055,45	0,13	22,65	18,79	4,3	1,98
	82	3058,15	0,06	17,49	31,58	5,5	1,98



5.2.2 Resistivity Index

The study involved measurement of RI at only one water saturation. This was done to cut experimental time that may otherwise be very long for porous plate drainage of low permeable samples. A fast evaporation technique [2] was used to obtain a precalculated water saturation of 40%.

Results are listed in the sheets below; raw data are included with the attached CD-ROM. "Best estimate" regression analysis data are listed in table 5.4.

Table 5.4. Archie's saturation exponent 'n' for the Tor Fm chalk in the Rigs-3 well.

Chalk formation	Archie's 'n' from linear regression
Tor Fm	1.87

Subject : End-point Resistivity Index data | **Well: Rigs-3**
Company : Hess DK | **GEUS Core Lab, 28.11.2007**

Brine d_w :	1,074	@ 25 °C
Brine d_w @ 40% dilution:	1,026	@ 25 °C
Brine R_w @ 40% dilution, ohmm	0,159	@ 25 °C

Dilution-evaporation method to determine Archie 'n' @ end-point Sw = 40% :

Plug no.	Material balance for diluted brine @ room conditions					Wet weight data for S_w = 40%		Plug resistivity data @ 1200 psi		
	Ø [%]	BV [cc]	PV [cc]	$WW_{meas.}$ [g]	$WW_{calc.}$ [g]	$WW_{meas.\ @\ 40\%}$ [g]	$WW_{calc.\ @\ 40\%}$ [g]	$\|Z_t\|$, ohm	Phase, deg.	RI
13	18,19	54,47	9,91	131,22	131,25	125,34	125,34	535,2	-1,70	5,47
39	21,65	55,21	11,95	129,79	129,83	122,70	122,70	308,1	-0,77	4,71
41	19,51	56,82	11,08	135,65	135,68	129,08	129,08	467,7	-1,15	5,71
74	23,02	55,25	12,71	128,55	128,60	121,02	121,02	347,2	-0,90	5,77
82	17,81	54,87	9,77	132,59	132,63	126,81	126,81	568,2	-1,45	5,75

NB: Due to poor electrode contact (high phase angle) samples had to be taken down, trimmed and re-measured for resistivity; this produced better results with lower phase angle, but necessitates that a new Z_0 be calculated:

Plug no.	Dimensional data after trim					Wet weight data for S_w = 40%		Corrected Z_0 @ 1200 psi		
	BV_i [cc]	BV_{trim} [cc]	$L_{calc\ trim}$ [cm]	$L_{caliper\ trim}$ [cm]	L_{trim} [cm]	WW before trim [g]	WW after trim [g]	$\|Z_0\|$ [ohm]		
13	54,47	53,31	4,727	4,722	4,725	125,34	122,68	97,8		
39	55,21	54,64	4,850	4,850	4,850	122,64	121,38	65,4		
41	56,82	55,93	4,956	4,964	4,960	129,00	126,99	82,0		
74	55,25	54,74	4,827	4,823	4,825	120,97	119,86	60,2		
82	54,87	53,60	4,720	4,725	4,723	126,76	123,83	98,9		

Plug no.	Imp data @ 1200 psi			
	Imp1 [ohm]	Imp2 [ohm]	Phase1 [deg]	Phase2 [deg]
13	536,0	535,0	-1,60	-1,80
39	309,1	307,7	-0,76	-0,77
41	468,0	468,0	-1,10	-1,20
74	348,0	347,0	-0,90	-0,90
82	570,0	567,0	-1,50	-1,40

Recorded S_w data after evaporation		
S_w [ml]	$PV_{1200\ psi}$ [ml]	$S_{w1200\ psi}$ [%]
3,96	9,75	40,7
4,72	11,80	40,0
4,36	10,84	40,2
5,04	12,52	40,3
3,86	9,63	40,1

Brine check	Date	Comment
[ohmm]	dd.mm.yy	
0,156	18.10.07	after 5-6 PV's
0,155		
0,156		
0,158		
0,155		

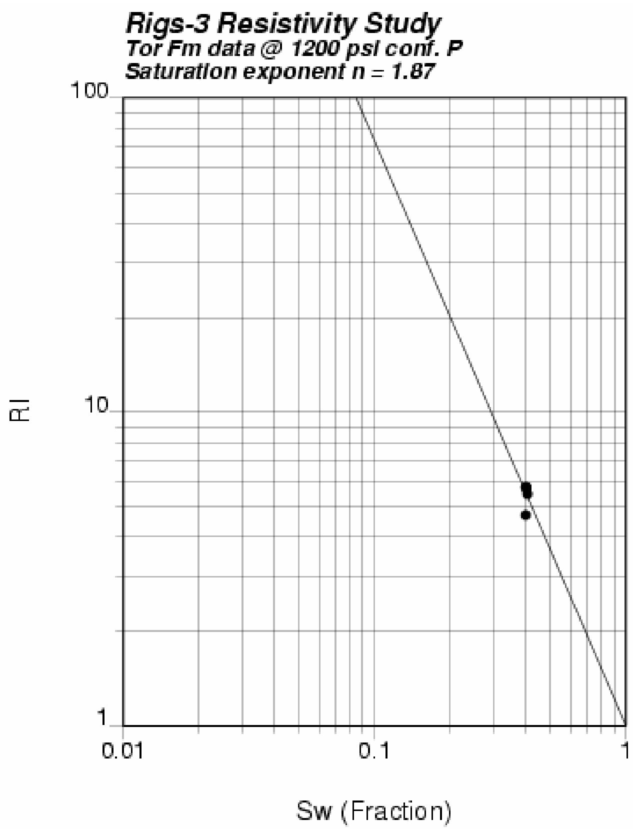
Subject : Resistivity Index — **Well: Rigs-3**

Company : Hess DK

Overburden RI data and saturation exponent 'n' — **GEUS Core Lab, 17.12.2007**

Reservoir unit:Tor Fm — **Regression 'n' : 1,87**

Well	Plug no.	Depth	Overburden data @ 1200 psi confining P			
		[m]	Ø [%]	Sw [%]	RI	Archie 'n'
Rigs-3	**13**	3035,10	17,9	40,7	5,47	1,89
	39	3043,77	21,4	40,0	4,71	1,69
	41	3044,51	19,1	40,2	5,71	1,91
	74	3055,45	22,7	40,3	5,77	1,93
	82	3058,15	17,5	40,1	5,75	1,91



Number of data 5
Number plotted 5

X Variable:
geom. mean 0.403
std. dev. 1.006

Y Variable:
geom. mean 5.466
std. dev. 1.080

Correlation 0.330
Rank correlation 0.300

Regression:
intercept 1.00
slope -1.87

6 References

1. Springer, Niels: Special Core Analysis for Amerada Hess Denmark. South Arne Field. Electrical properties.
   Geological Survey of Denmark and Greenland Report no. 24, 2005. Confidential.

2. N. Springer, U. Korsbech, H.K. Aage: Resistivity Index Measurement without the Porous Plate: A Desaturation Technique Based on Evaporation Produces Uniform Water Saturation Profiles and More Reliable Results for Tight North Sea Chalk.
   Intl SCA Symp.,Pau, (September 2003), paper SCA 2003-38, p. 459-470.

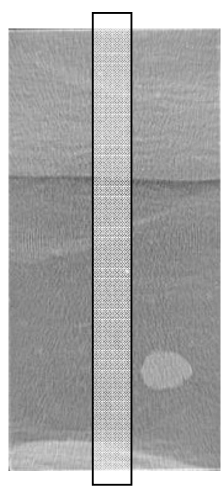
4. SCA Guidelines for sample preparation and porosity measurement of electrical resistivity samples, part I-IV.
   The Log Analyst, **31**, 1 & 2, 1990.

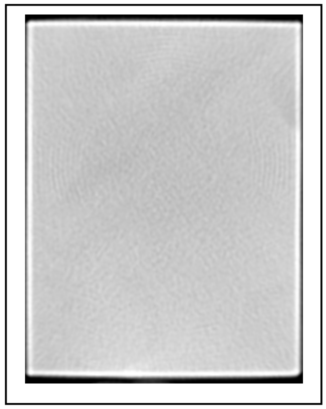
7 Plug quality screening

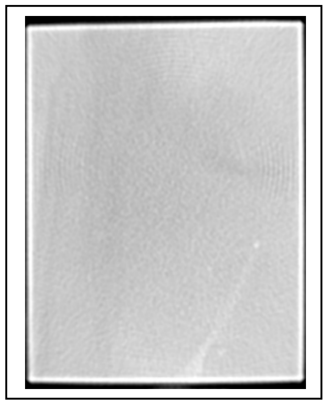
7.1 Scanning parameters:

Sellar-ear	Ultra High
120 kV	330 mAs
Time=	2 s
Slice=	4 mm

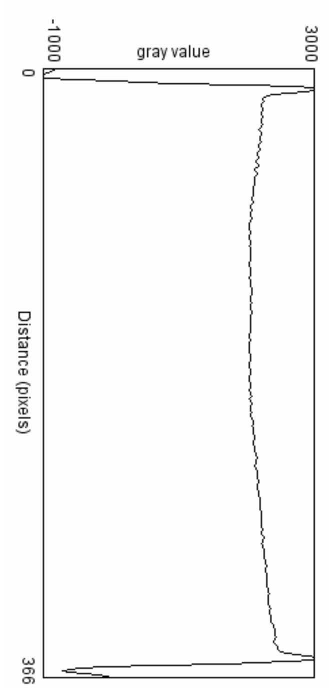
The images below are close to real plug size and represent 2 longitudinal cuts perpendicular to each other through the plug sample. The thickness of each slice is 4 mm. To the right is shown the spectral (grey tone) distribution of an approx. 1 cm broad cut through each slice (cf. the figure below) to visualize the matrix homogeneity and structural elements. The distance axis corresponds to the length of the sample image, the grey scale is in Hounsfield units; -1000 represents air (100% porosity), +3000 is dense matrix (0% porosity). The average grey tone figure for the longitudinal cuts is given in the info box; this figure is proportional to the sample porosity.

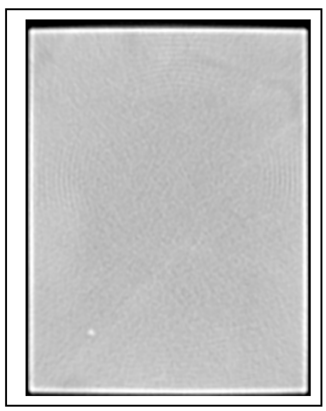




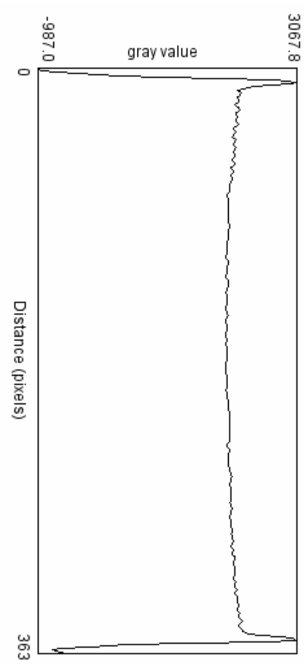


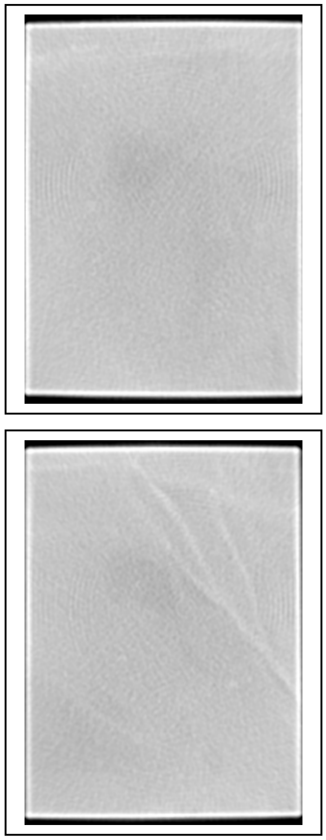
Plug 13,   Depth: 3035.10 [m]
2 perpendicular cuts,
Mean gray value: 2236
Porosity   :   18.0 [%]



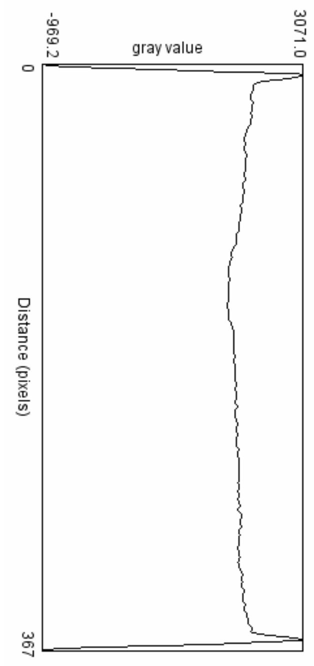


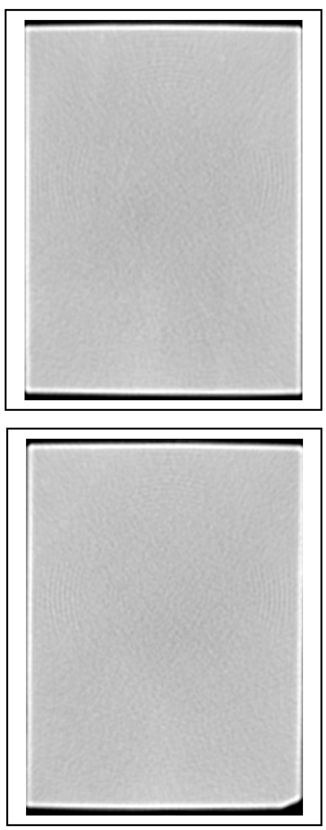
Plug 25,   Depth: 3039.13 [m]
2 perpendicular cuts,
Mean gray value: 2094
Porosity   :   21.7 [%]



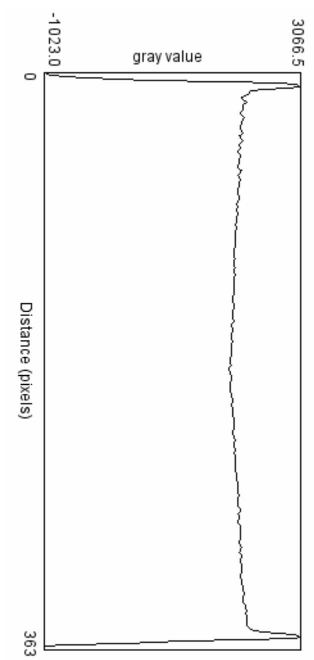


Plug 32, Depth: 3041.45 [m]
2 perpendicular cuts,
Mean gray value: 2165
Porosity : 20.0 [%]

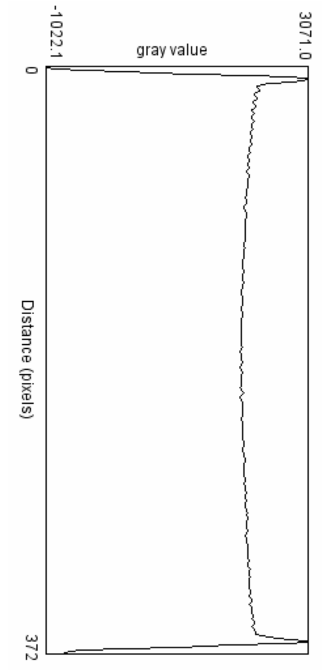




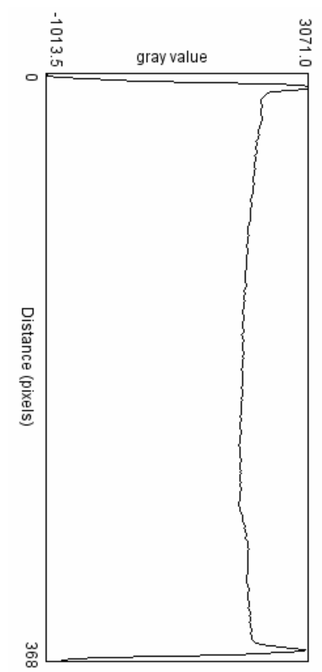
Plug 39, Depth: 3043.77 [m]
2 perpendicular cuts,
Mean gray value: 2105
Porosity : 21.3 [%]

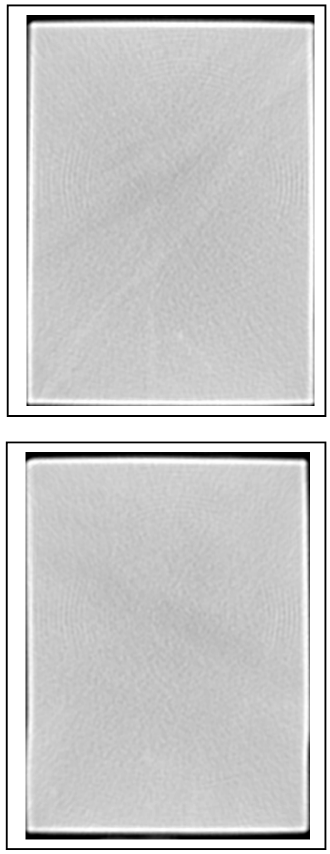


Plug 41,   Depth: 3044.51 [m]
2 perpendicular cuts,
Mean gray value: 2170
Porosity   :   19.0 [%]

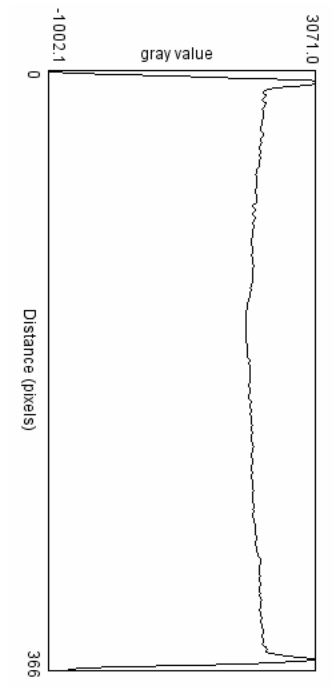


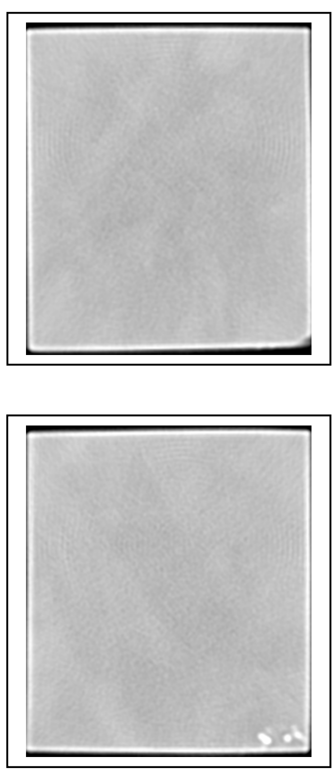
Plug 42,   Depth: 3044.75 [m]
2 perpendicular cuts,
Mean gray value: 2204
Porosity   :   18.3 [%]



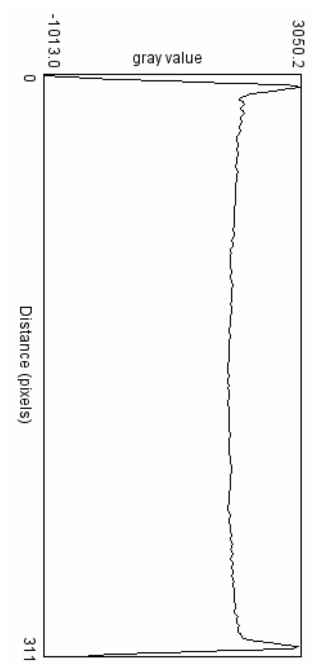


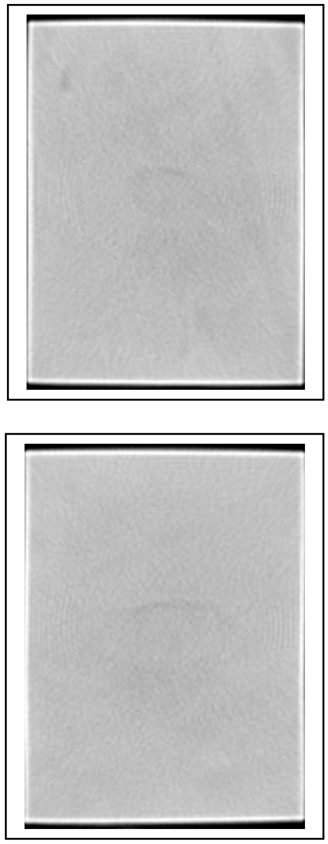
Plug 46, Depth: 3046.16 [m]
2 perpendicular cuts,
Mean gray value: 2213
Porosity : 18.2 [%]



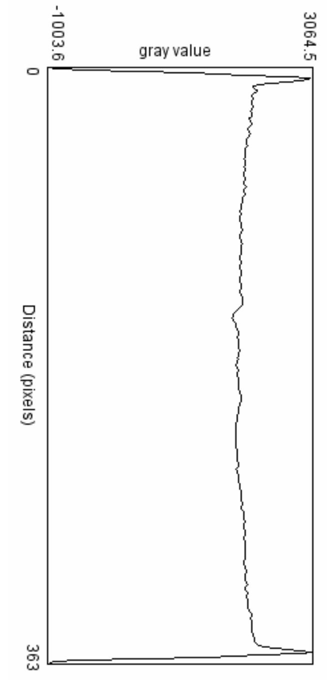


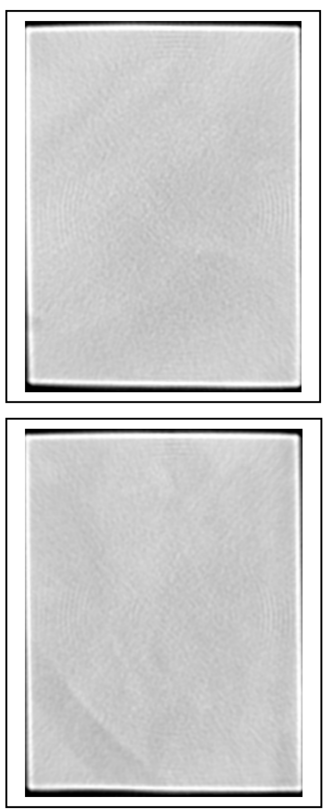
Plug 61, Depth: 3051.30 [m]
2 perpendicular cuts,
Mean gray value: 2055
Porosity : 23.3 [%]





Plug 74, Depth: 3055,45 [m]
2 perpendicular cuts,
Mean gray value: 2062
Porosity : 22.3 [%]





Plug 82, Depth: 3058.15 [m]
2 perpendicular cuts,
Mean gray value: 2287
Porosity : 17.5 [%]