DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2002/74

Special Core Analysis for Mærsk Olie og Gas A/S

Well: Igor G-2X

Mercury injection capillary pressure and electrical measurements

Niels Springer

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

G E U S

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2002/74

Special Core Analysis for Mærsk Olie og Gas A/S

Well: Igor G-2X

Mercury injection capillary pressure and electrical measurements

Niels Springer
Core Laboratory

Released 30.06.2005

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

GEUS

Contents

Enclosure: - Data on CD-ROM

Req. no.: 09251-470
File: Igor2x_SCALrep.doc
Igor2x_electrical.xls
Igor2x_Hg-injdata.xls
g2xscal.dat

1 Introduction

By request of Mærsk Olie og Gas A/S, GEUS Core Laboratory has performed special core analysis on the Igor G-2X well, Danish North Sea.

The experimental programme was specified in a facsimile message from Mr. David Steer, dated August 3, 1999. The following analytical programme has been carried out:

- Screening of plugs for SCAL
- Formation resistivity factor measurement at overburden conditions
- Resistivity index measurement at overburden conditions
- Mercury injection capillary pressure at overburden conditions

This study is carried out under contract GSC 1418, CWO 173. Preliminary SCAL data have been reported to Mærsk during the period August 2000 to October 2001. The resistivity index was measured using two different methods, the RICI technique and the traditional porous plate drainage. Focus is on the porous plate data with the RICI data being included for comparison. For some types of chalk the RICI technique has been found to be unreliable as further explained in section 5.

2 Sampling and analytical procedures

In collaboration with Mærsk Olie og Gas and based on the conventional core analysis data [1] in total 33 plugs, covering both the Danian and the Maastrichtian section of the core, were selected for the special core analysis (SCAL) study, ref. table 2.1.

2.1 Plug quality screening

The total SCAL plug set were X-ray CT-screened using the scanning facility at Department of Chemical Engineering, the Technical University of Denmark. Two longitudinal cuts perpendicular to each other is recorded for each plug. Scanning images are attached to section 5.3.

2.2 Electrical measurements

From inspection of the scanning images the most homogeneous plugs were selected for the electrical measurements, table 2.1. Plugs were next vacuum and pressure saturated in simulated formation brine, table 2.2, and then left to equilibrate in an anaerobic jar for several weeks.

The pore volume compressibility was recorded during a period of 24 hours while the confining sleeve pressure was increased from 150 psi to 800 psi. During the following 2-3 days regular measurements of the plug resistivity R_0 at $S_w = 1$ was carried out until stable readings were obtained. Data for the formation resistivity factor FRF and cementation exponent m are contained in section 5.1.

Next the electrical resistivity cells were dismantled and porous plates specified @ 15 bar were installed in the downstream end of the plugs. A confining pressure of 800 psi was again applied, and measurement of the resistivity index was performed in a sequence of pressure steps from 30 to 90 psi. Isopar-L® refined mineral oil was used as the displacing non-wetting phase. After completion of the measurements the plug samples were Dean Starked to obtain a proper determination of the end-point water saturation S_{wf}, and remeasured for conventional core analysis data.

With a view to the discouraging results obtained from the RICI experiment, two slightly different measurement strategies were followed for the porous plate experiment:

- One group of samples comprising plug 6, 45, 81, 83 and 98 were measured during a period of 3 weeks, i.e. comparable to the effective injection time for the RICI experiments.
- Another group of samples comprising plug 5, 13, 19, 25 and 34 were measured during a period of ½ year to get as close to drainage equilibrium as practically possible and thus test the claims put forward in a paper by Lyle and Mills [2]

Data for the resistivity index RI and saturation exponent n are contained in section 5.2.

2.3 Mercury injection capillary pressure

A set of 21 plugs of diameter 38 mm was used for mercury injection capillary pressure measurement. Plugs were installed in core holders at 800 psi net confining pressure and both the injection and withdrawal curve was measured from vacuum to 2000 psi. A stepwise constant pressure measurement regime was applied and total analytical time was 2-4 days per plug sample. Reservoir Laboratories A/S carried out this study, and the results are given in a separate report (no. 2077/64-00).

SCAL test	Danian D1 unit	Maastrichtian M1 unit
FRF and RI:	5, 13, 19, 25, 34,	81, 98
Hg-injection:	2, 7, 11, 17, 22, 27, 32, 37, 42, 46, 52	57, 62, 67, 72, 77, 87, 92, 97, 102, 107
Reserve:	38, 47, 53	64, 89

Table 2.1. Igor G-2X, 33 plugs were X-ray CT-screened and a number of plugs were later taken for the specified special core analysis tests. During the SCAL programme it was decided to include a few additional plugs not previously screened (6, 45 and 83).

Element	Concentration
	mg/l
Na total	17300
Na+	17300
Na+	0
K+	135
Mg2+	475
Ca2+	1370
Ca2+	
Ca2+	
Sr2+	120
Ba2+	
Cl-	30707
HCO3-	0

TDS: 50107

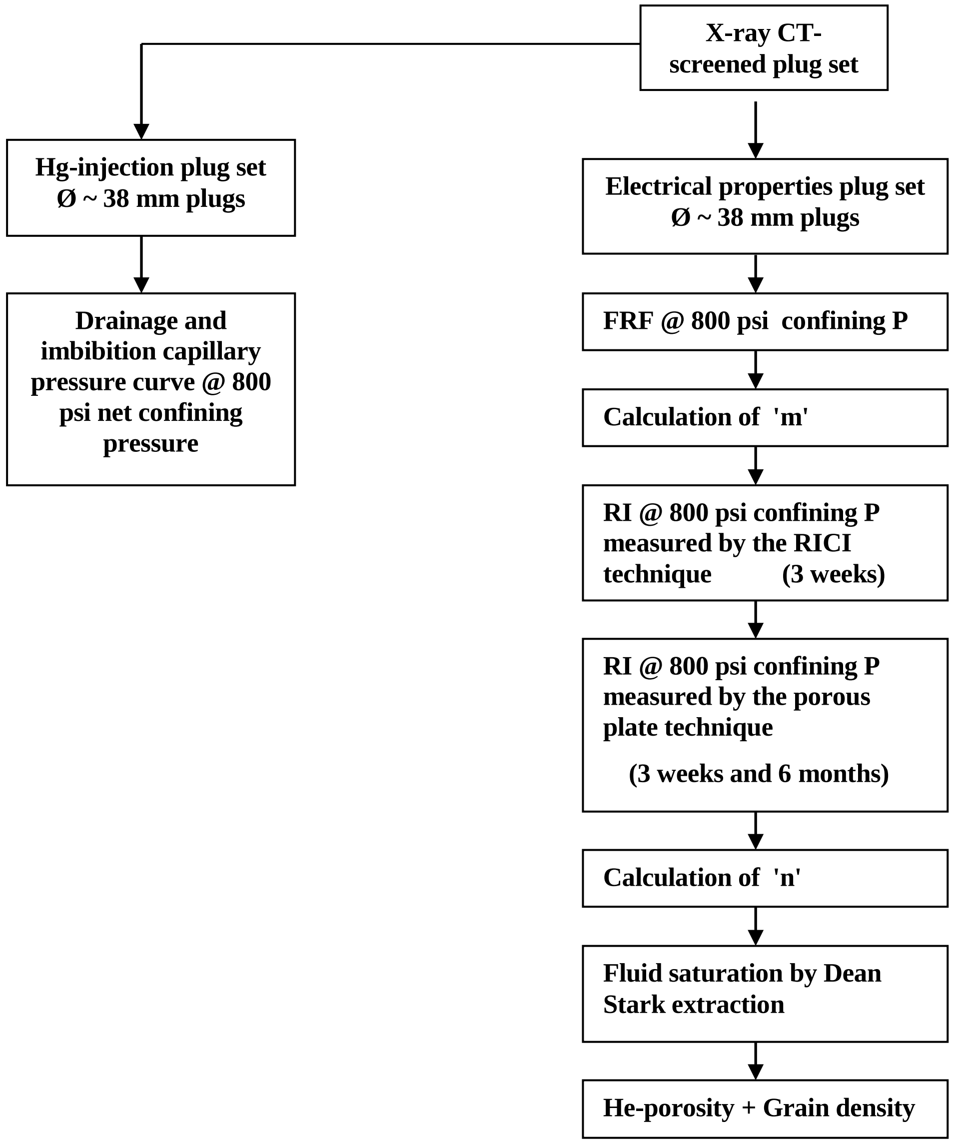
Physical data:		
	Measured R_w	0.131 ohmm @ 25 C
	Calculated R_w	0.129 ohmm @ 25 C
	Measured d_w	1.031 g/ml @ 25 C
	Calculated d_w	1.032 g/ml @ 25 C

pH: 7.7 @ 23 °C

Table 2.2. Igor G-2X, chemical and physical data for the simulated formation brine. No formation water analysis is available from the Igor field. The chemical composition is formulated by GEUS Core Laboratory based on Tyra formation water composition and information from Mærsk Olie og Gas on the assumed R_w = 0.065 ohm meter @ 160 °F for the central part of Igor.

$NaHCO_3$ is excl. from the reciepe, but the brine equilibrated with crushed chalk

3 Flow diagram of the analytical procedures



4 Analytical Methods

For an explanation of the routine core analysis methods, please refer to the conventional core analysis report [1].

Electrical measurements are performed at 25 ± 1 ºC, and to the guidelines established by the Society of Core Analysts [3].

4.1 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 of the resistivity cell design (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 specially designed standard cell. The standard cell is calibrated using a suitable conductivity standard solution delivered by a recognised chemical company. The measured formation brine resistivity is checked against a model calculated resistivity.

4.2 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 should produce a straight line from which the saturation exponent n can be determined as the slope.

The measurement of RI involves desaturation in a porous plate cell, therefore the measurement of RI is conveniently combined with air/brine or oil/brine capillary pressure experiments 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 is recorded consecutively. 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.

When the desaturation (capillary pressure measurement) is conducted in single sample cells, the advantage is that the experiment does not need to be interrupted to determine the water saturation, which is necessary in the traditional multi sample pressure pot experiment. The disadvantage is that the resistivity measurement will include the porous plate as well as the sample. The effect of the porous plate, which can be significant, must be corrected for. This problem has been solved by a special electrode arrangement that electrically short cuts the porous plate. After completion of the RI measurement the porous plate is removed and the end point resistance checked to make sure that the porous plate measurement is not biased.

5. Results

5.1 Formation resistivity factor data

Formation / Chalk unit	Plug no.	Porosity Ø @ 800 psi	Formation factor FRF	Cementation exponent m
Ekofisk / Danian D1	5	37.70	7.0	2.02
	6	39.14	6.3	
	13	36.49	7.6	
	19	37.26	7.2	
	25	35.25	8.4	
	34	33.92	8.9	
	45	31.97	10.4	
Tor / Maastrichtian M1	81	32.44	7.3	1.86
	83	26.62	12.9	
	98	34.19	7.2	

Table 5.1. Igor G-2X, analytical data corrected for pore volume compressibility. Basic data are shown in the tables below.

Nomenclature

L	– sample length [cm]
D	– sample diameter [cm]
BV	– bulk volume [cc]
PV	– pore volume [cc]
GV	– grain volume [cc]
GD	– grain density [g/cc]
DW	– dry weight [g]
WW	– wet weight [g]
Ø	– porosity [pct. or fraction]
S_w	- water saturation [pct. or fraction]
S_{wf}	- final water saturation [pct. or fraction]
S_{wir}	- irreducible water saturation [pct. or fraction]
F or FRF	– formation resistivity factor
RI	– resistivity index
RICI	– resistivity index by continuous injection
m	– cementation exponent
n	– saturation exponent
a	– Archie constant, normally a=1
R_0	- resistivity of water saturated sample [ohm meter]
R_w	- resistivity of formation water [ohm meter]
Z_0	- impedance of formation water saturated sample [ohm]
Z_t	- impedance of sample at $S_w < 1$[ohm]
P_d	- displacing phase pressure [psi]
PP	– porous plate

Subject: Electrical properties **Well: Igor-G2X**
Company: Mærsk Olie og Gas A/S **GEUS Core Lab, 15.09.2002**

Brine density, g/ml: 1,031 Oil density, g/ml: 0,763

Plug no.	Depth	CCAL data				Data after careful plug trim								Mass balance data		
	feet	BV, cc	Dry wt., g	Porosity, %	GD, g/cc	L, mm	D, mm	Dry wt., g	Wet wt., g	BV', cc	PV1, cc	PV2, cc	Delta PV, cc	M_{grain}, g	M_{fluid}, g	ΣM_{plug}, g
5	6620,00	56,18	94,02	38,28	2,710	47,65	37,94	90,28	111,53	53,96	20,66	20,61	0,04	90,24	21,30	111,53
13	6628,17	60,44	103,17	37,13	2,711	52,50	37,99	101,45	124,18	59,47	22,08	22,05	0,03	101,36	22,77	124,13
19	6634,92	59,21	100,17	37,65	2,713	51,73	37,92	98,69	121,27	58,31	21,95	21,90	0,05	98,63	22,63	121,27
25	6642,00	48,25	84,37	35,58	2,712	41,64	38,03	82,30	99,62	47,10	16,76	16,80	-0,04	82,29	17,28	99,56
34	6652,00	51,69	91,93	34,36	2,710	44,39	38,03	89,77	107,57	50,43	17,33	17,26	0,06	89,71	17,86	107,58
6	6621,08	60,48	98,24	40,05	2,707	53,04	38,05	97,24	122,18	59,95	24,01	24,19	-0,18	97,30	24,75	122,05
45	6664,00	47,45	86,87	32,42	2,706	41,51	38,11	86,44	102,15	47,31	15,34	15,24	0,10	86,52	15,81	102,33
81	6813,83	57,02	103,77	33,09	2,707	49,91	38,02	101,91	121,50	56,56	18,71	19,00	-0,29	102,43	19,29	121,73
83	6816,00	54,38	108,10	26,76	2,710	47,42	38,11	107,23	122,11	54,12	14,48	14,43	0,05	107,41	14,93	122,33
98	6831,00	36,07	63,70	34,86	2,711	31,69	38,05	63,29	76,19	35,83	12,49	12,51	-0,02	63,28	12,88	76,15

PV1: pore volume calculated from He-porosity measurement
PV2: pore volume calculated from wet-dry plug wt.

Remarks: Please observe that a set of 10 plugs have been measured for RI by drainage in porous plate single resistivity cells; data for these plugs are found in spreadsheets indexed RI 5, …., RI 98
Another set of 5 plugs have been measured for RI by the RICI technique (continous injection) also in single resistivity cells; data for these plugs are found in spreadsheets indexed
RICI 5, ….. , RICI 34

Table 5.2. Igor G-2X, conventional and mass balance data for the selected plug set to be measured for electrical parameters. Formation factor data appears from the table below.

Subject: Electrical properties | **Well: Igor G-2X** | **Formation Resistivity Factor data**

Company: Mærsk Olie og Gas A/S | **GEUS Core Lab, 15.09.2002**

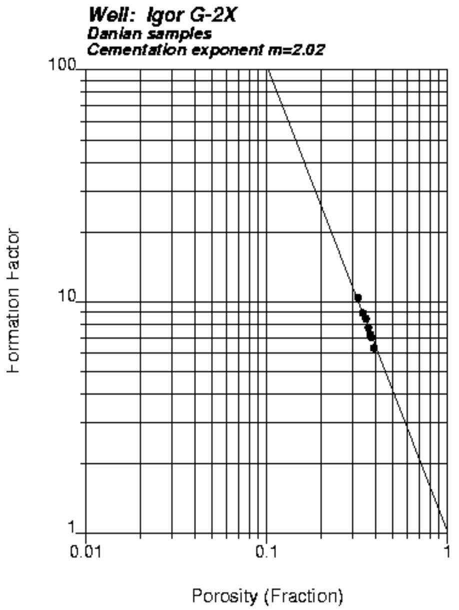
Brine density, g/m 1.031 Brine resistivity, ohmm: 0.131 @ 25 C Plug impedance measured @ 10 kHz

Plug no.	SCAL data			Overburden data @ 800 pi			Plug resistivity data @ 800 psi				
	BV', cc	PV1, cc	Ø , %	Δ PV800 psi, cc	PV800 psi, cc	Ø 800psi, %	L800 psi, cm	A800 psi, cm2	|Zo|, ohm	Phase, deg.	FRF
5	53.96	20.66	38.28	0.50	20.16	37.70	4.750	11.25	38.58	-0.98	7.0
13	59.47	22.08	37.13	0.60	21.48	36.49	5.232	11.25	46.56	-1.15	7.6
19	58.31	21.95	37.65	0.36	21.59	37.26	5.162	11.23	43.36	-1.72	7.2
25	47.10	16.76	35.58	0.24	16.52	35.25	4.157	11.27	40.58	-0.90	8.4
34	50.43	17.33	34.36	0.33	17.00	33.92	4.429	11.31	45.74	-0.43	8.9
6	59.95	24.01	40.05	0.89	23.12	39.14	5.278	11.19	38.70	-1.11	6.3
45	47.31	15.34	32.42	0.31	15.03	31.97	4.142	11.35	49.57	-0.88	10.4
81	56.56	18.71	33.09	0.54	18.17	32.44	4.975	11.26	42.04	-0.80	7.3
83	54.12	14.48	26.76	0.10	14.38	26.62	4.739	11.40	70.46	-0.32	12.9
98	35.83	12.49	34.86	0.36	12.13	34.19	3.158	11.23	26.38	-1.00	7.2

Raw data					
Imp1, ohm	Imp2, ohm	Imp3, ohm	Phase1, deg.	Phase2, deg.	Phase3, deg.
38.40	37.95	39.38	-1.02	-1.00	-0.93
46.67	46.20	46.80	-1.26	-1.22	-0.96
43.31	42.97	43.81	-1.66	-1.63	-1.86
40.78	40.49	40.46	-0.99	-0.97	-0.73
45.59	45.34	46.28	-0.41	-0.37	-0.50
38.76	38.71	38.63	-1.12	-1.10	-1.10
49.63	49.60	49.47	-0.89	-0.88	-0.88
42.10	42.04	41.97	-0.81	-0.80	-0.80
70.54	70.50	70.33	-0.33	-0.33	-0.31
26.40	26.39	26.36	-1.00	-1.00	-1.00

PV1: pore volume calculated from He-porosity measurement

BV' : bulk volume from mercury submersion



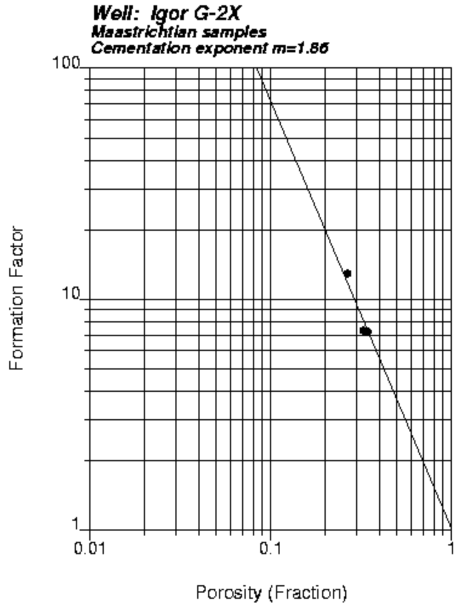
Number of data 7
Number plotted 7

X Variable:
geom. mean 0.359
std. dev. 1.066

Y Variable:
geom. mean 7.889
std. dev. 1.168

Correlation -0.997
Rank correlation -1.000

Regression:
intercept 1.00
slope -2.02



Number of data 3
Number plotted 3

X Variable:
geom. mean 0.309
std. dev. 1.114

Y Variable:
geom. mean 8.785
std. dev. 1.312

Correlation -0.984
Rank correlation -1.000

Regression:
intercept 1.00
slope -1.86

5.2 Resistivity index data

Background: In the original CWO from Mærsk, GEUS Core Laboratory was asked to perform resistivity index measurements by the RICI technique on a set of 10 plugs for a period of 3 weeks. A low injection rate of 0.1 ml/h was decided for and the experiment initiated without a porous plate in the downstream end of the plug. However, with the low injection rate water saturations below 70% were not reached, meaning a poor determination of the saturation exponent. It was therefore decided to increase the injection rate stepwise to obtain lower water saturations, and the first 5 plugs were then completed in 4 weeks. During this period peculiar and unexpected low saturation exponent data were obtained from other RICI studies for Mærsk running synchronously with the Igor study. It was therefore decided to re-measure the whole set of plugs using the traditional porous plate technique. Two different experimental designs were used:

- One set of 5 plugs (6, 45, 81, 83 and 98) were drained down in a series of constant pressure steps until 90 psi during 3 weeks, i.e. for a period comparable to the requested RICI experiment.
- Another set of 5 plugs (5, 13, 19, 25 and 34) were drained down in a series of constant pressure steps until 85 psi during 6 months getting as close a practically possible to drainage equilibrium. This period is 2-3 times as long as normally spent by a service company on this type of SCAL test.

Observations: The first plug set measured during 3 weeks display curved or S-shaped patterns in the RI regression diagrams. Lyle and Mills for non-uniform core saturations have predicted such behaviour in a paper [2]. The results obtained for the Igor samples in the short-term experiment completely verify the Lyle and Mills model. However, as will be pointed out below it is not the Igor plugs that are the limiting factor, but the 15 bar porous plates that do not allow the water to drain fast enough in the short time allotted to each pressure step. A bank of water is piled up in front of the porous plate and this is the explanation for the curved lines observed in the RI measurements.

The second plug set demonstrates that the 2-3 weeks allotted to each pressure step allows close to equilibrium conditions to be obtained before RI is measured. The endpoint is especially well determined allowing for 6 weeks drainage time. As opposed to the short-term data, the long-term measurements display close to straight regression lines in the diagrams.

For comparison the first measured RICI plug set (5, 13, 19, 25 and 34) is attached to the report. Except for plug 5 the agreement with the long term porous plate experiment is striking, indicating a very good reproducibility between two different techniques for the same set of plugs. It also shows that there is no prevailing end-effect in the RICI test for the present Igor plugs contrary to the fact that the RICI test performed here is a simple oil-flooding (no porous plate fitted) that normally would lead to a piling-up of water in the downstream end of the plug. However, from other experiments it is known that for the lower porosity Danian chalk end-effects occur and the simple RICI test can not generally be recommended for electrical measurements of chalk. In a RICI test **with** porous plate fitted, which is the normal practice, the low permeability of the plate would inevitably lead to a non-uniform water distribution in short term experiments. In this respect there is no difference between the RICI and the porous plate techniques.

Data reduction: In the paper by Lyle & Mills [2] the endpoint at S_{wir} is identified as being close to uniform water saturation. In the short-term experiments there is no guarantee that equilibrium has been obtained at the endpoint, but the sudden curvature of the line in the RI diagrams could indicate that the system is rapidly approaching equilibrium. Otherwise the determination of the endpoint water saturation is precise because the Dean Stark determination reflects the final water saturation and there is a second check of the resistivity without the porous plate fitted. In the data reduction a weighing procedure has therefore been introduced in which the endpoint is weighed 5 times relative to other points in the regression analysis. This is believed to give a better estimate of the "true" saturation exponent. Regression data for raw and weighed data are given in the attached diagrams in section 5.2.

Subject: Electrical properties | **Well: Igor-G2X** | **Saturation exponent data**

Company: Mærsk Olie og Gas A/S | **GEUS Core Lab, 15.09.2002**

Brine density, g/ml: 1,031 Brine resistivity, ohmm: 0,131 @ 25 C Plug impedance measured @ 10 kHz

Oil density, g/ml: 0,763

Dead volume: 2,96 ml (only applicable to plug no. 6-98)

Plug no.	Depth	Data after careful plug trim						Data after PP test ref. @ 800 psi								
	feet	L, mm	D, mm	Dry wt., g	Wet wt., g	BV', cc	PV1, cc	Wet wt., g	Grav. Prod., ml	Swf 1	Vol. Prod., ml	V. Prod-Dead V., ml	Swf 2	DS, ml H2O	Dean Stark Swf	Applied Swf, %
5	6620,00	47,65	37,94	90,28	111,53	53,96	20,66	108,25	12,24	0,41	14,10	14,10	0,30	6,10	0,30	30
13	6628,17	52,50	37,99	101,45	124,18	59,47	22,08	119,79	16,38	0,26	16,30	16,30	0,24	4,90	0,23	23
19	6634,92	51,73	37,92	98,69	121,27	58,31	21,95	116,78	16,75	0,24	17,15	17,15	0,21	4,00	0,19	20
25	6642,00	41,64	38,03	82,30	99,62	47,10	16,76	97,03	9,66	0,42	10,75	10,75	0,35	5,00	0,30	32
34	6652,00	44,39	38,03	89,77	107,57	50,43	17,33	104,81	10,30	0,41	11,70	11,70	0,31	4,70	0,28	29
6	6621,08	53,04	38,05	97,24	122,18	59,95	24,01	117,27	18,32	0,24	20,95	17,99	0,22	5,20	0,22	22
45	6664,00	41,51	38,11	86,44	102,15	47,31	15,34	99,41	10,22	0,33	16,05	13,09	0,13	4,60	0,31	31
81	6813,83	49,91	38,02	101,91	121,50	56,56	18,71	117,04	16,64	0,11	19,00	16,04	0,12	2,05	0,11	11
83	6816,00	47,42	38,11	107,23	122,11	54,12	14,48	119,04	11,46	0,21	14,30	11,34	0,21	2,60	0,18	19
98	6831,00	31,69	38,05	63,29	76,19	35,83	12,49	73,25	10,97	0,12	14,70	11,74	0,03	1,40	0,12	12

Plug no.	Saturation exponent data @ 800 psi confining P			
	Porosity	Porous plate test		RICI test
	Ø 800psi, %	n (meas.)	n (weighed)	n (meas.)
5	37,70	1,81	1,73	1,95
13	36,49	1,77	1,71	1,79
19	37,26	1,84	1,76	1,75
25	35,25	1,71	1,58	1,62
34	33,92	1,70	1,63	1,69
6	39,14	1,88	1,77	
45	31,97	1,89	1,71	
81	32,44	1,79	1,70	
83	26,62	1,87	1,67	
98	34,19	2,10	1,83	

Danian plugs, mean n = 1.70 *

Maastrichtian plugs, mean n =1.73 *

* weighed data

The applied final water saturation Swf is calculated from the Dean Stark Swf and the volumetric production Swf2 with the weight being on the Dean Stark value. The gravimetric Swf1 value has been found to be unreliable probably due to small grain loss problems.

5.2.1 Short term porous plate data

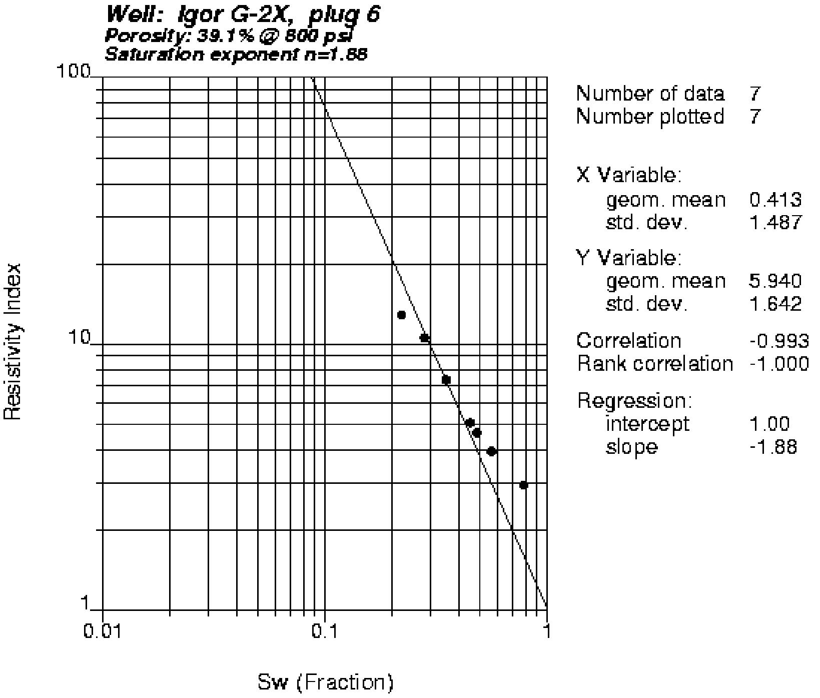
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**

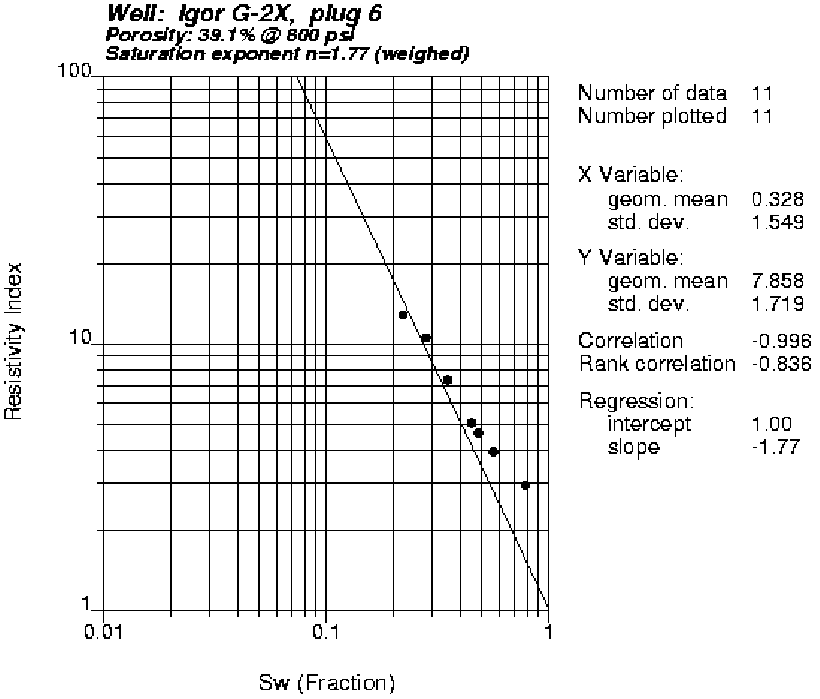
Plug resistivity data @ 800 psi:

Plug no.: **6**
Depth: **6621.08 feet**
Formation: Danian

$|Z_0|$, ohm : 38.70

P_d, psi	S_w, %	$\|Z_t\|$, ohm	Phase, deg.	RI
90	22	496	-0.70	12.82
90	28	406	-0.80	10.49
70	35	282	-0.70	7.29
60	45	195	-0.80	5.04
60	48	178	-0.85	4.60
60	56	151.8	-0.96	3.92
60	78	113.2	-1.15	2.93



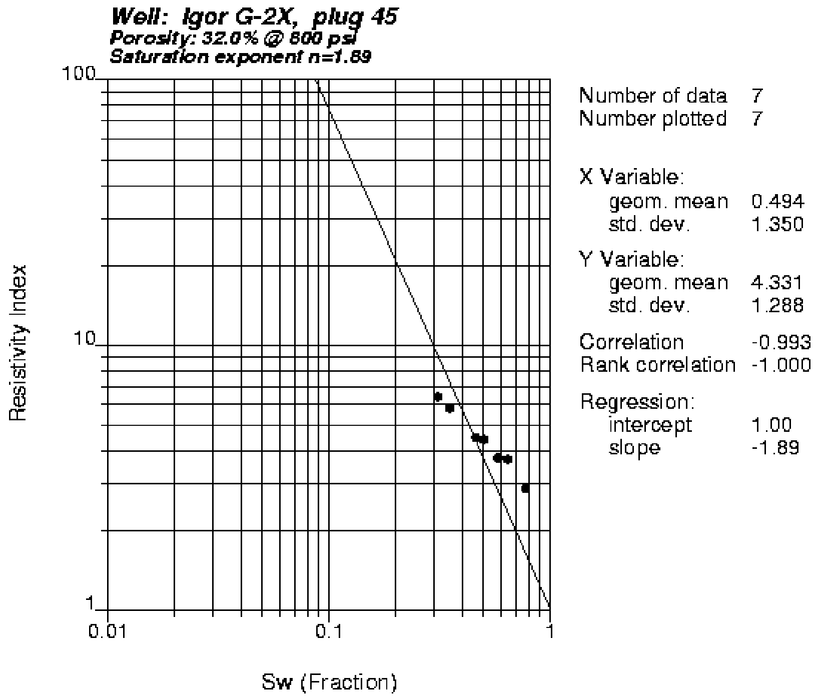


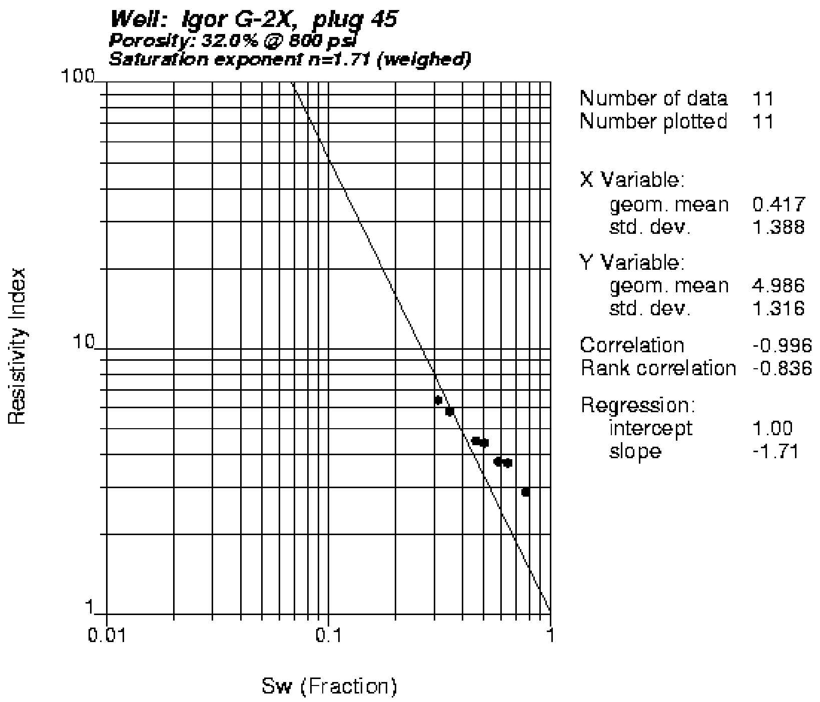
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**
Plug resistivity data @ 800 psi:

Plug no.: 45
Depth: 6664.00 feet
Formation: Danian

|Z_0|, ohm : 49.57

P_d, psi	S_w, %	$\|Z_t\|$, ohm	Phase, deg.	RI
90	31	316	-1.40	6.38
90	35	285	-2.09	5.75
70	46	222	-1.60	4.48
70	50	217	-1.70	4.38
60	58	186	-1.80	3.75
60	64	183.5	-2.20	3.70
50	77	141.7	-2.40	2.86





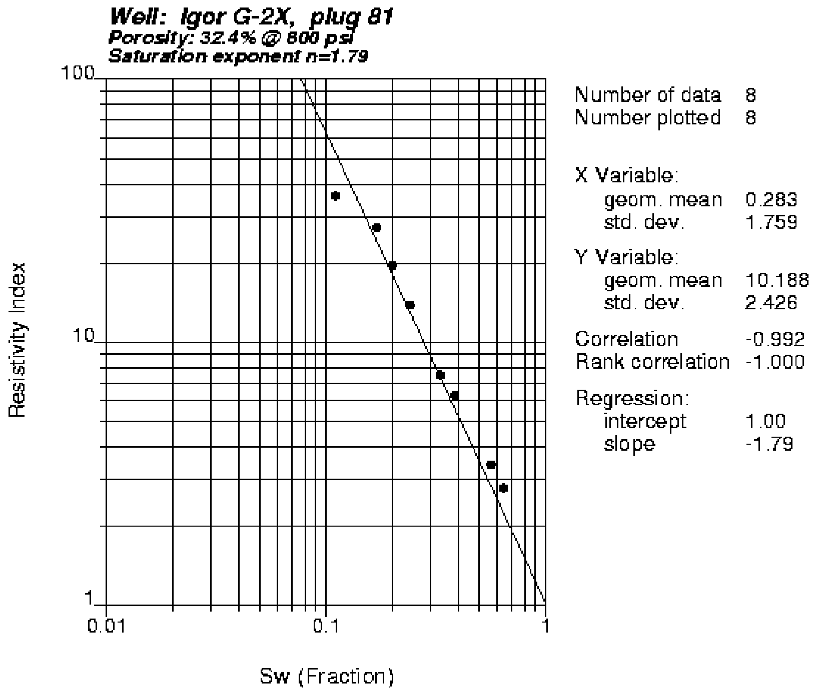
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**

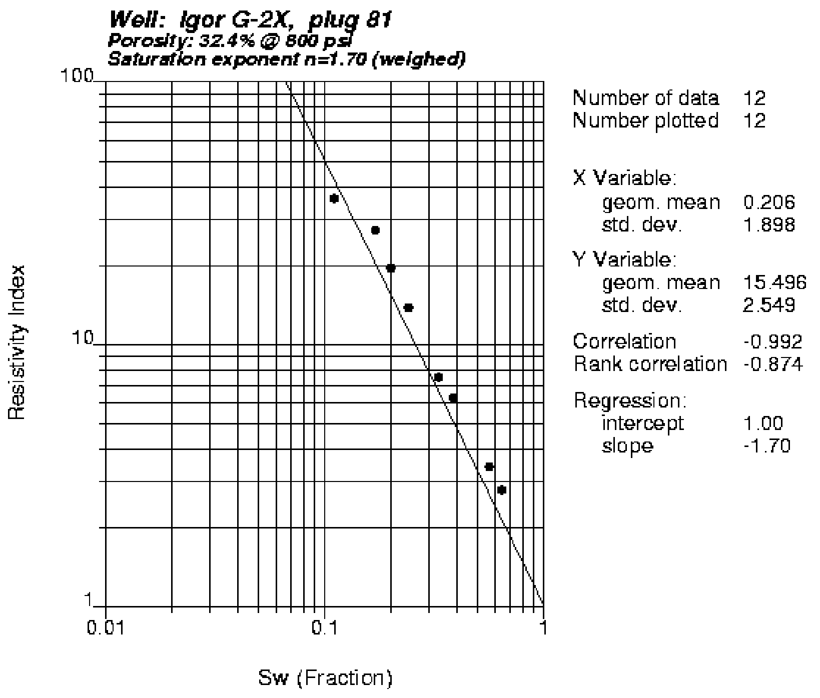
Plug resistivity data @ 800 psi:

Plug no.: 81
Depth: 6813.83 feet
Formation: Maastrichtian

$|Z_0|$, ohm : 42.04

P_d, psi	S_w, %	$\|Z_t\|$, ohm	Phase, deg.	RI
90	11	1507	-1.19	35.85
90	17	1143	-1.30	27.19
70	20	820	-1.10	19.51
60	24	580	-1.20	13.80
50	33	315	-1.67	7.49
50	38.5	262	-1.90	6.23
50	56	143.5	-3.03	3.41
40	64	116.8	-2.71	2.78



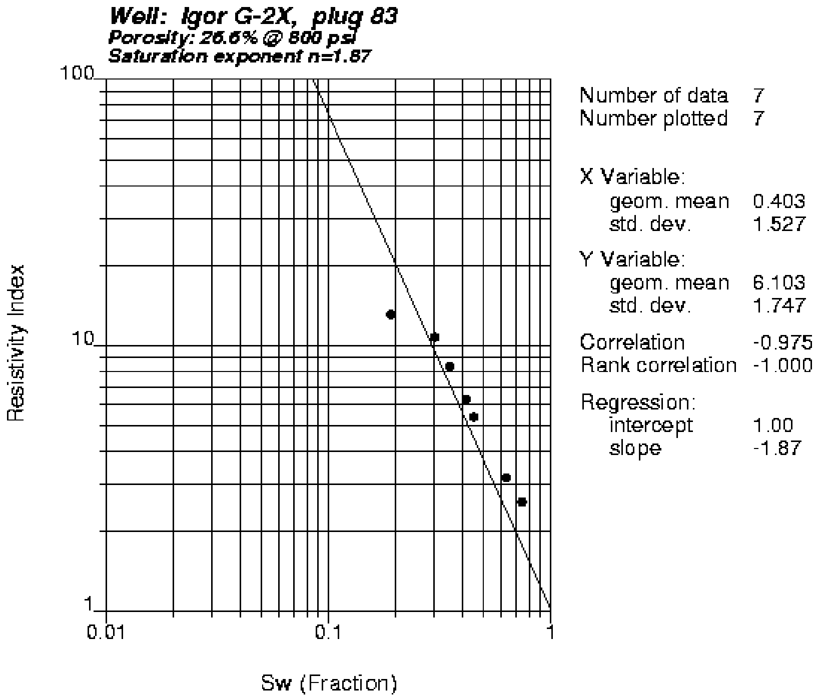


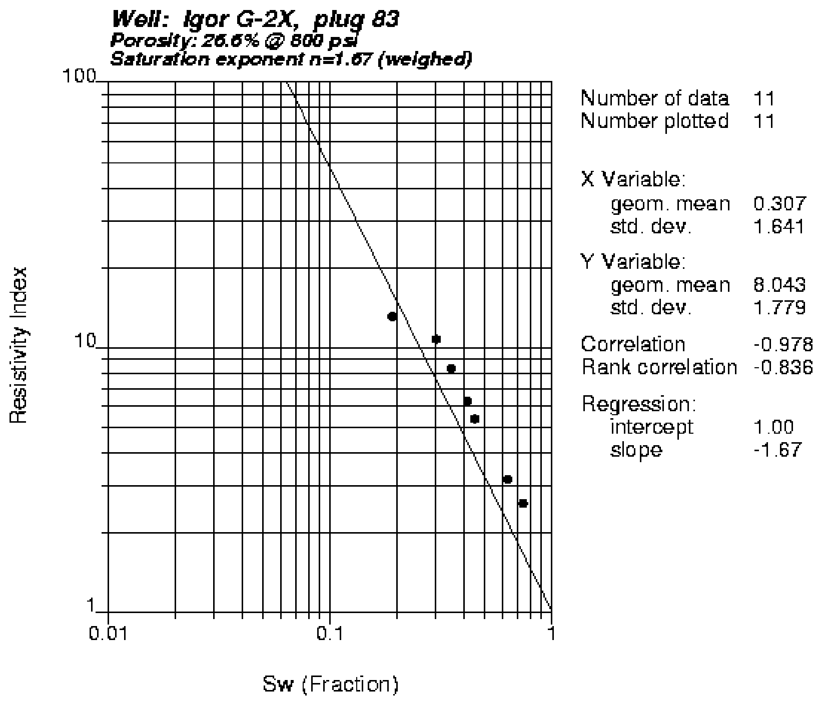
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**
Plug resistivity data @ 800 psi:

Plug no.: 83
Depth: 6816.00 feet
Formation: Maastrichtian

|Z_0|, ohm : 70.46

P_d, psi	S_w, %	$\lvert Z_t \rvert$, ohm	Phase, deg.	RI
90	19	919	-0.90	13.04
90	30	752	-1.00	10.67
70	35	586	-0.80	8.32
60	41.5	441	-0.80	6.26
60	45	376	-0.90	5.34
50	63	223	-0.96	3.17
50	74	181	-1.10	2.57





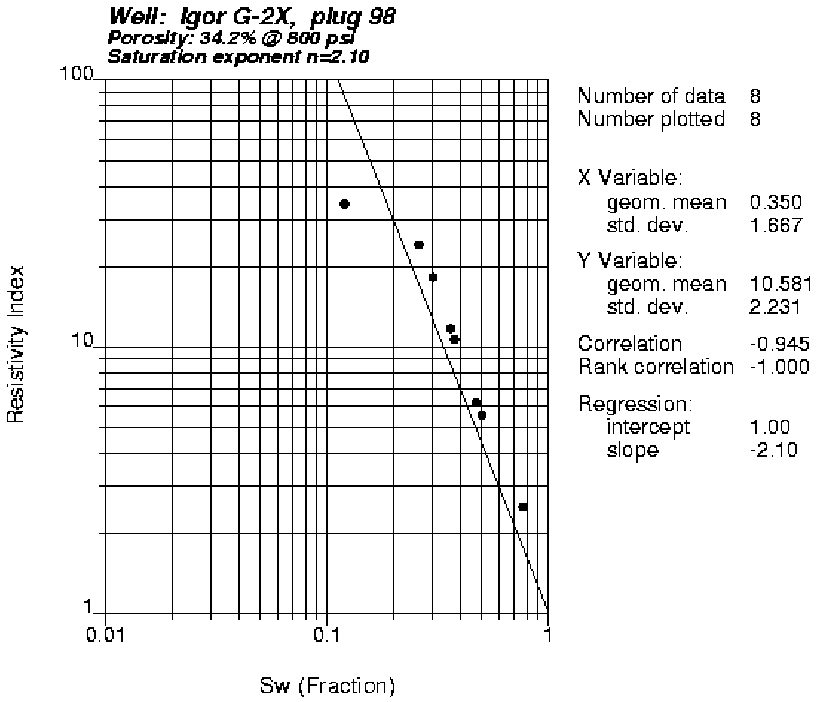
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**

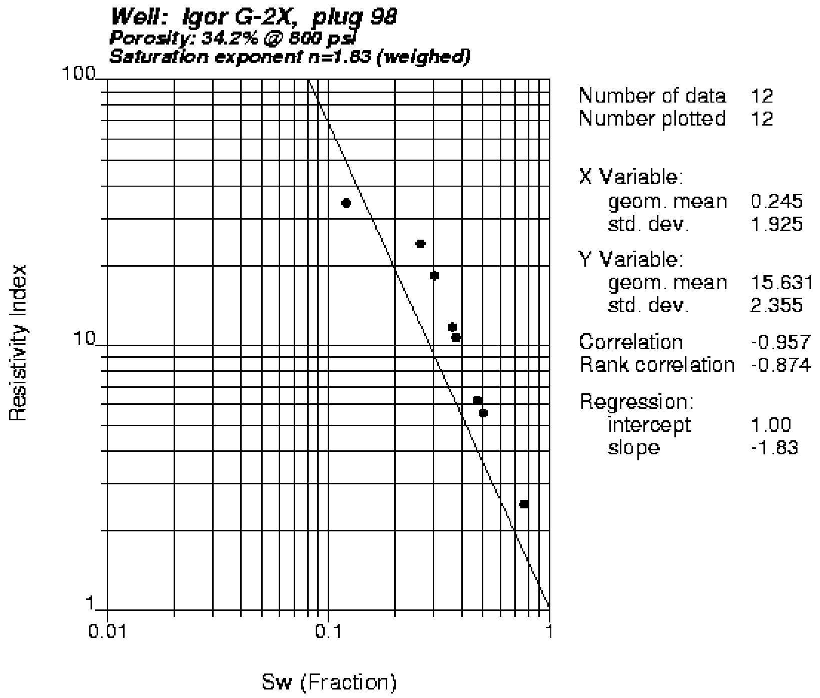
Plug resistivity data @ 800 psi:

Plug no.: 98
Depth: 6831.00 feet
Formation: Maastrichtian

$|Z_0|$, ohm : 26.38

P_d, psi	S_w, %	$\|Z_t\|$, ohm	Phase, deg.	RI
90	12	900	-0.90	34.11
90	26	636	-0.80	24.11
70	30	481	-0.60	18.23
60	36	307	-0.50	11.64
60	37.5	280	-0.59	10.61
50	47	162.5	-0.52	6.16
50	50	145.4	-0.60	5.51
40	76.5	66.05	-0.72	2.50





5.2.2 Long term porous plate data

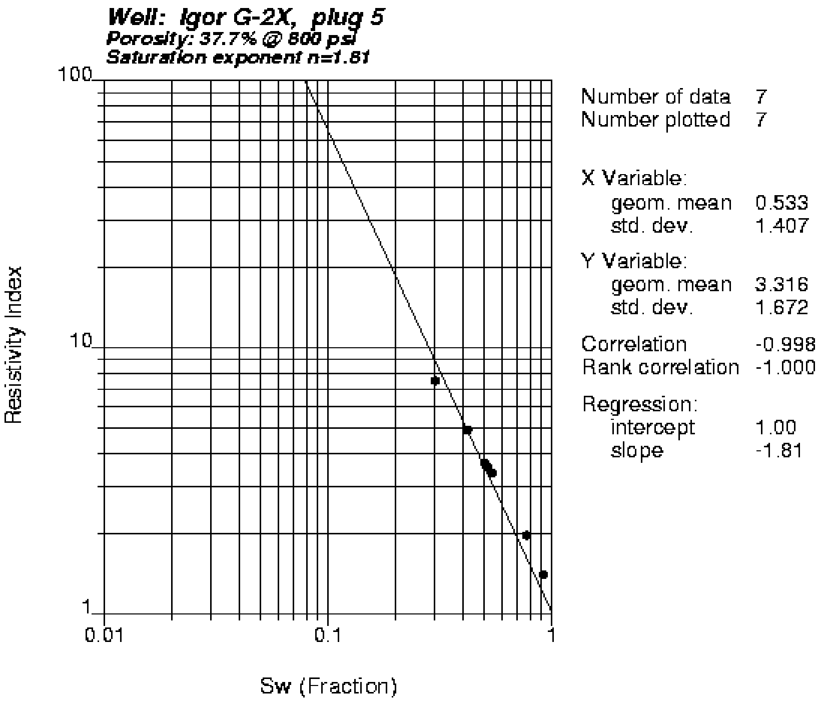
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**

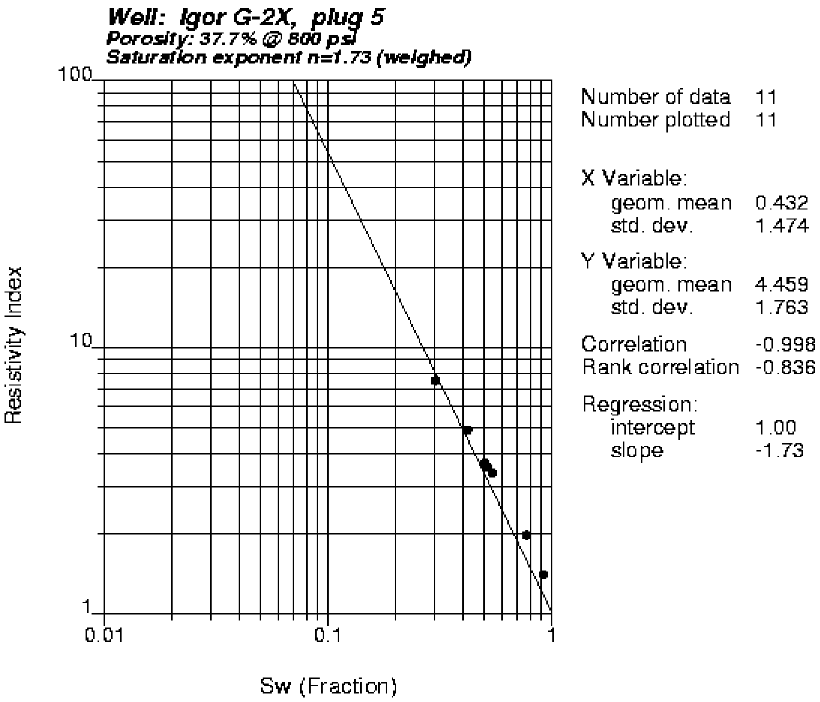
Plug resistivity data @ 800 psi:

Plug no.: **5**
Depth: **6620.00 feet**
Formation: Danian

$|Z_0|$, ohm : 38.58

P_d, psi	S_w, %	$\lvert Z_t \rvert$, ohm	Phase, deg.	RI
85	30	289	-1.00	7.49
80	42	187.9	-0.71	4.87
75	50	142	-0.59	3.68
70	51	137.2	-0.65	3.56
65	54	129.5	-0.69	3.36
60	77	75.6	-0.61	1.96
55	91	54.2	-0.60	1.40





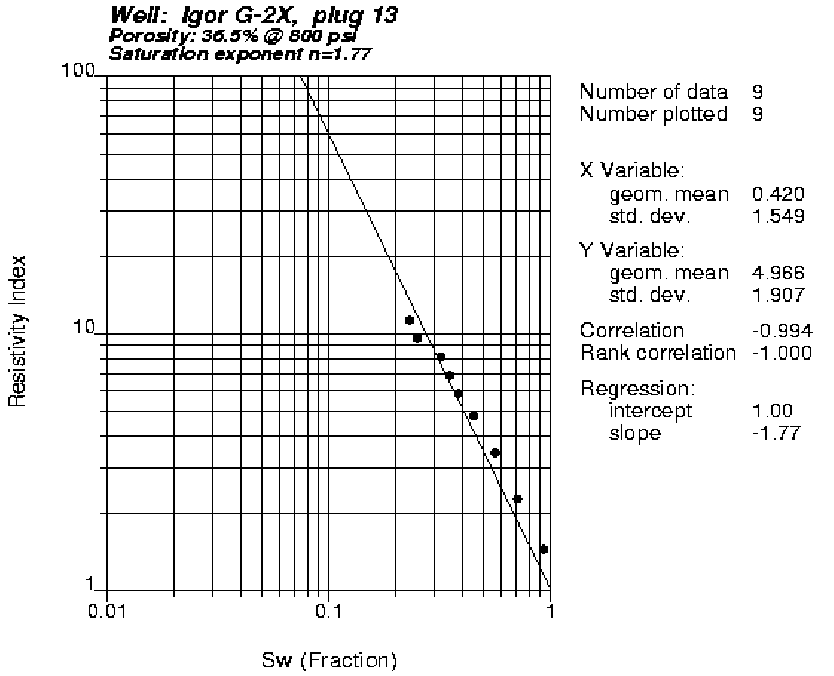
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**

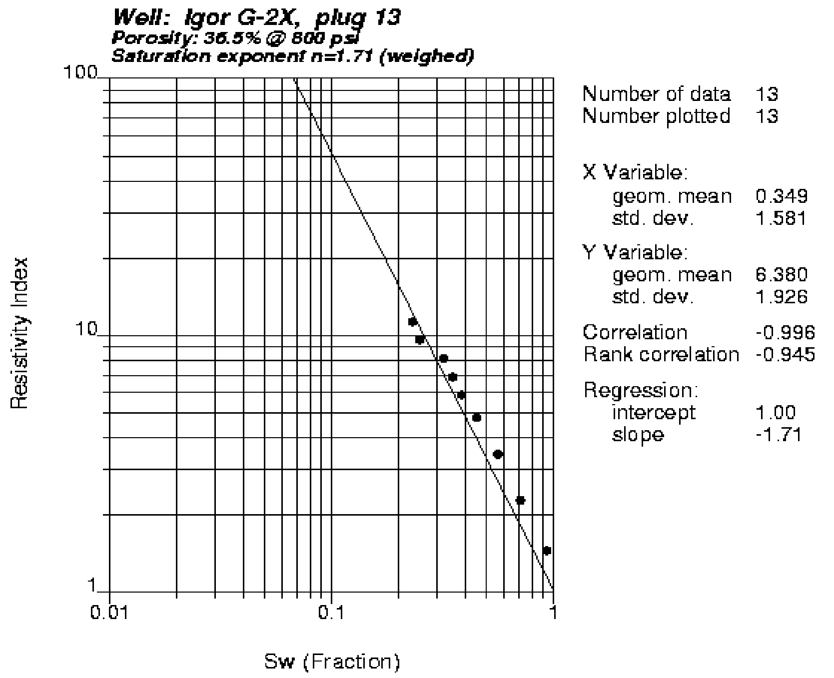
Plug resistivity data @ 800 psi:

Plug no.: 13
Depth: 6628.17 feet
Formation: Danian

$|Z_0|$, ohm : 46.56

P_d, psi	S_w, %	$\|Z_t\|$, ohm	Phase, deg.	RI
85	23.0	522	-0.80	11.21
80	25.0	444	-0.70	9.54
75	32.0	376	-0.60	8.08
70	35.0	320	-0.60	6.87
65	38.5	272	-0.50	5.84
60	45.0	221	-0.50	4.75
55	56.0	160	-0.48	3.43
50	70.5	105	-0.55	2.26
45	92.5	67	-0.76	1.44





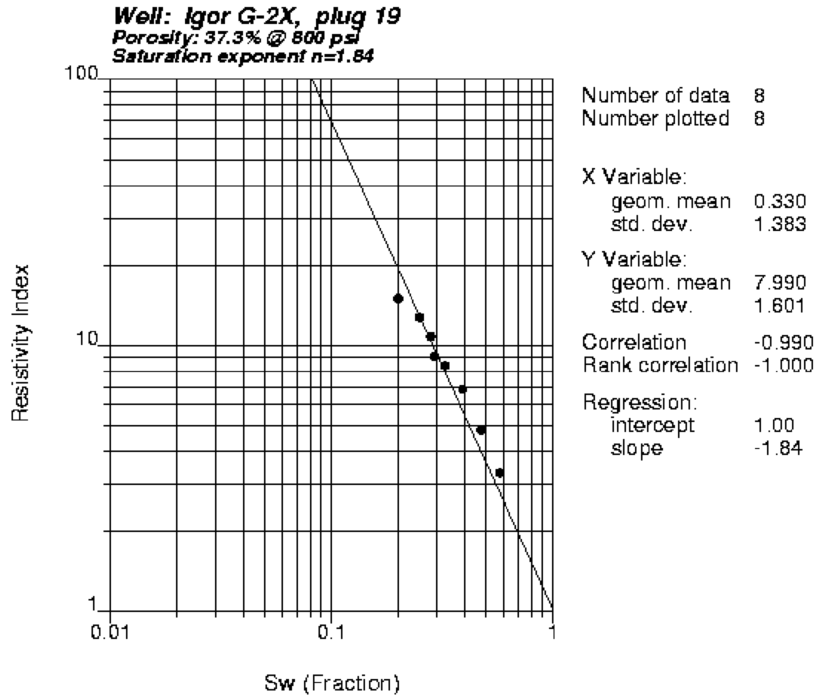
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**

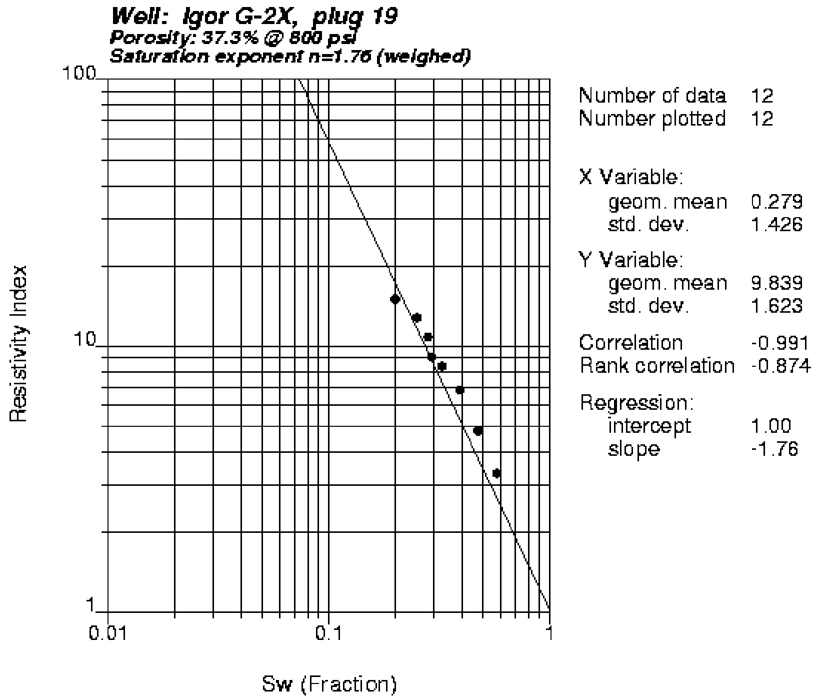
Plug resistivity data @ 800 psi:

Plug no.: 19
Depth: 6634.92 feet
Formation: Danian

$|Z_0|$, ohm : 43.36

P_d, psi	S_w, %	$\|Z_t\|$, ohm	Phase, deg.	RI
85	20	647	-0.80	14.92
80	25	552	-0.70	12.73
75	28	466	-0.60	10.75
70	29	392	-0.60	9.04
65	32.5	361	-0.60	8.33
60	39	295	-0.50	6.80
55	47.5	208	-0.50	4.80
50	57.50	143.60	-0.53	3.31





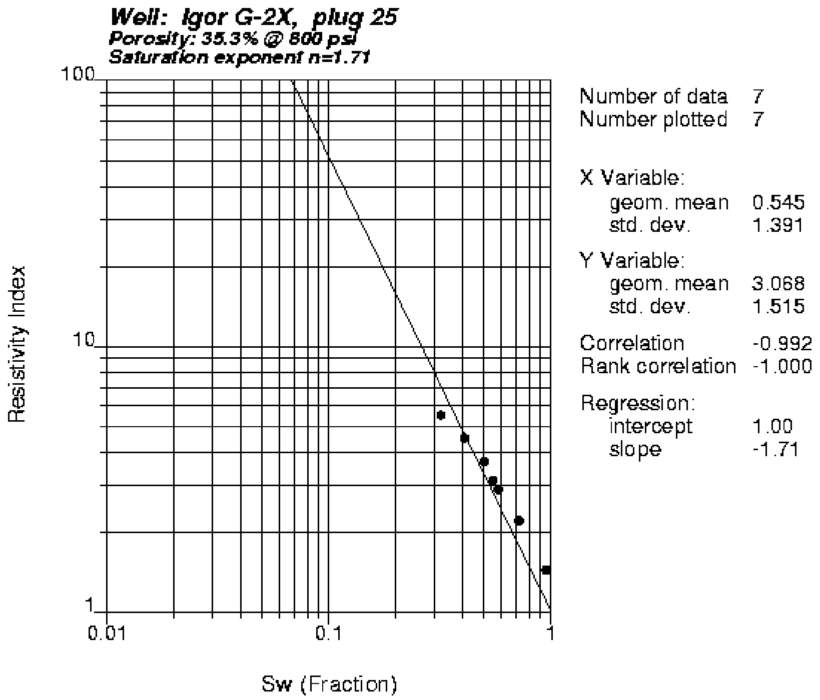
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**

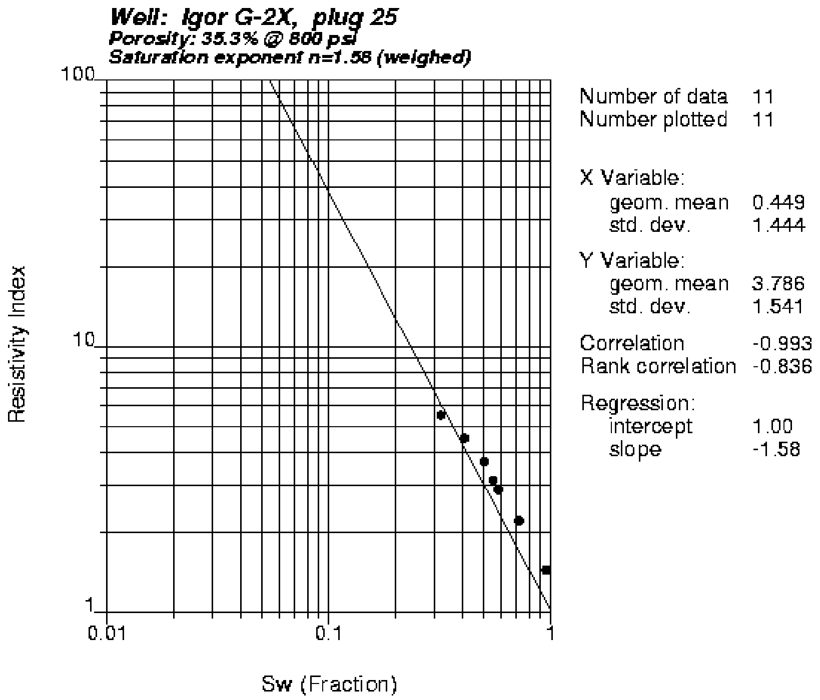
Plug resistivity data @ 800 psi:

Plug no.: 25
Depth: 6642.00 feet
Formation: Danian

|Z0|, ohm : 40.58

Pd, psi	Sw, %	|Zt|, ohm	Phase, deg.	RI
85	32	222	-1.00	5.47
80	41	182	-1.20	4.49
75	50	148.5	-1.40	3.66
70	55	127.1	-1.66	3.13
65	58	117.1	-1.84	2.89
60	72	89.11	-2.27	2.20
55	95	58.04	-3.20	1.43



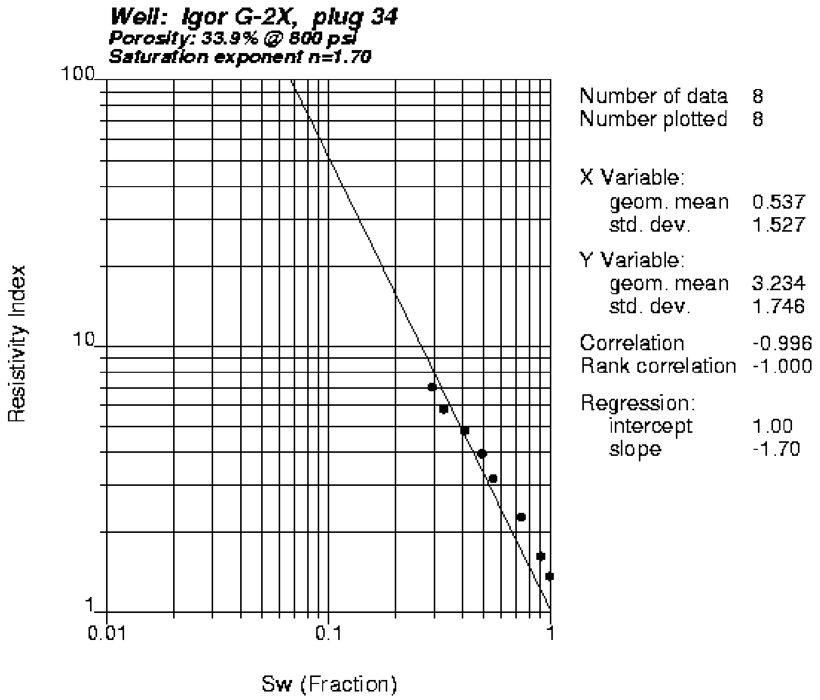


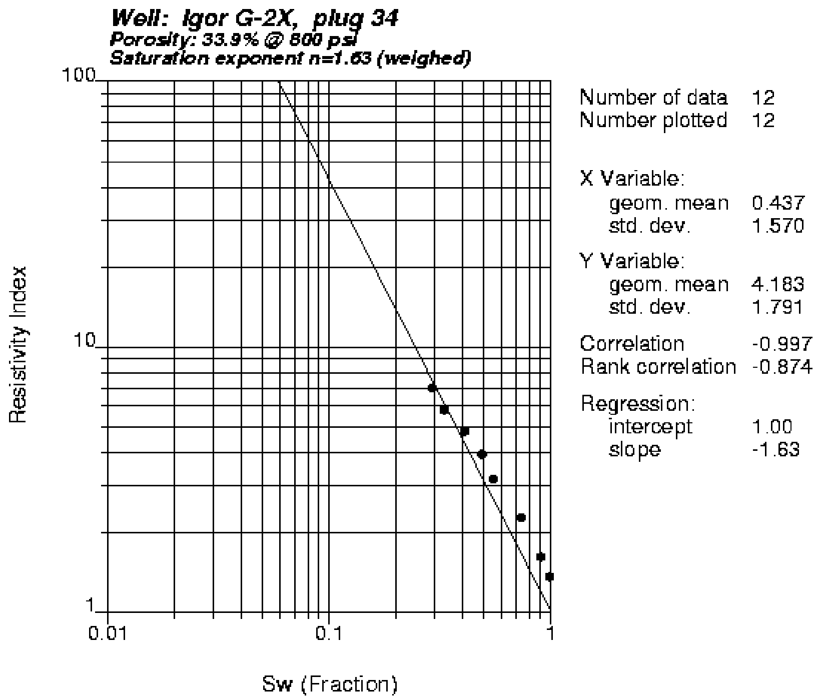
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**
Plug resistivity data @ 800 psi:

Plug no.: 34
Depth: 6652.00 feet
Formation: Danian

|Z0|, ohm : 45.74

Pd, psi	Sw, %	|Zt|, ohm	Phase, deg.	RI
85	29	320	-0.80	7.00
80	33	263.5	-0.80	5.76
75	41	219	-0.80	4.79
70	49	180	-0.80	3.94
65	55	144.5	-0.85	3.16
60	73.5	104	-0.94	2.27
55	90	73.83	-1.25	1.61
50	98.50	62.15	-1.35	1.36





5.2.3 RICI data

Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**

Plug resistivity data @ 800 psi:

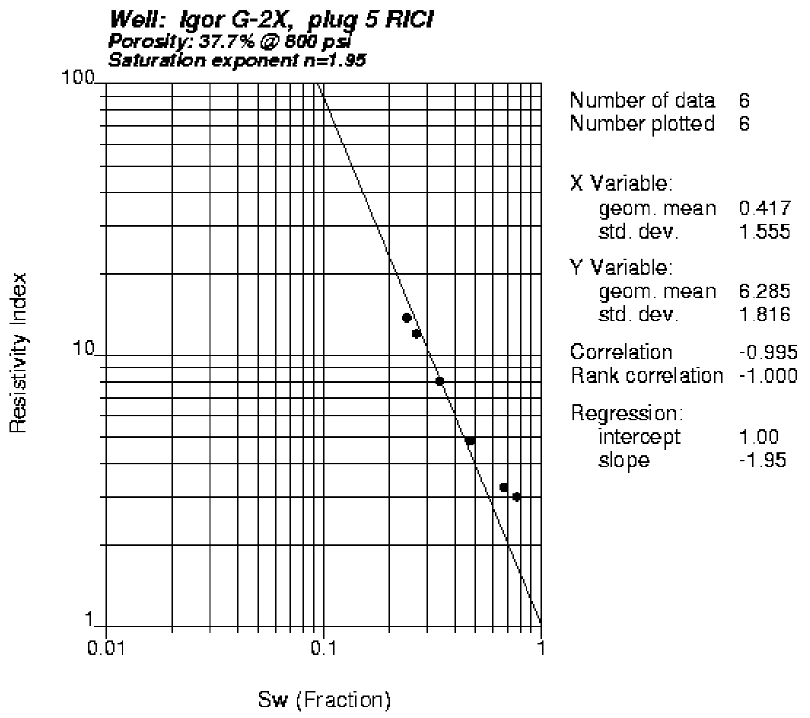
Plug no.: 5

Depth: 6620,00 feet

Formation: Danian

$|Z_0|$, ohm : 38,58

Inj. rate, ml/h	S_w, %	$\lvert Z_t \rvert$, ohm	Phase, deg.	RI
60,0	24	530	-2,50	13,74
30,0	26,5	462	-2,30	11,98
10,0	34	307,9	-2,13	7,98
3,0	47	185,9	-2,16	4,82
0,1	67	125,6	-1,34	3,26
0,1	77	115,8	-1,37	3,00



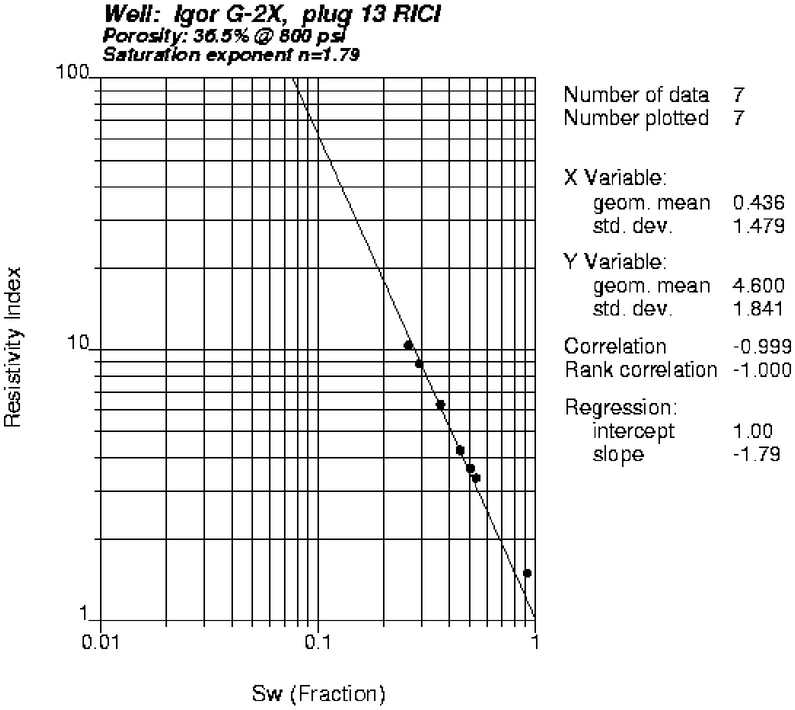
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**

Plug resistivity data @ 800 psi:

Plug no.: **13**
Depth: **6628,17 feet**
Formation: Danian

$|Z_0|$, ohm : 46,56

Inj. rate, ml/h	S_w, %	$\lvert Z_t \rvert$, ohm	Phase, deg.	RI
60,0	26,0	481	-0,90	10,33
30,0	29,0	412	-0,90	8,85
10,0	36,5	290,7	-0,81	6,24
3,0	45,0	197,7	-0,83	4,25
1,0	50,0	168,5	-0,84	3,62
0,3	53,0	155,9	-0,57	3,35
0,1	91,5	69	-0,86	1,49



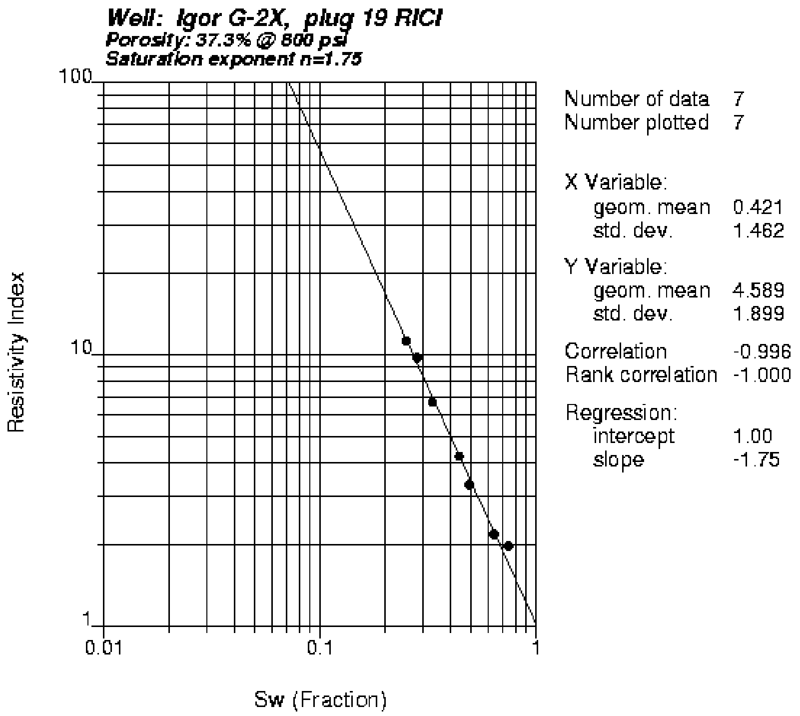
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**

Plug resistivity data @ 800 psi:

Plug no.: 19
Depth: 6634,92 feet
Formation: Danian

$|Z_0|$, ohm : 43,36

Inj. rate, ml/h	S_w, %	$\|Z_t\|$, ohm	Phase, deg.	RI
60,0	25	484	-1,20	11,16
30,0	28	421	-1,20	9,71
10,0	33	288,4	-1,24	6,65
3,0	44	181,9	-1,40	4,19
1,0	49	143,4	-1,52	3,31
0,3	63,5	94,19	-1,38	2,17
0,1	74	85,21	-1,89	1,97



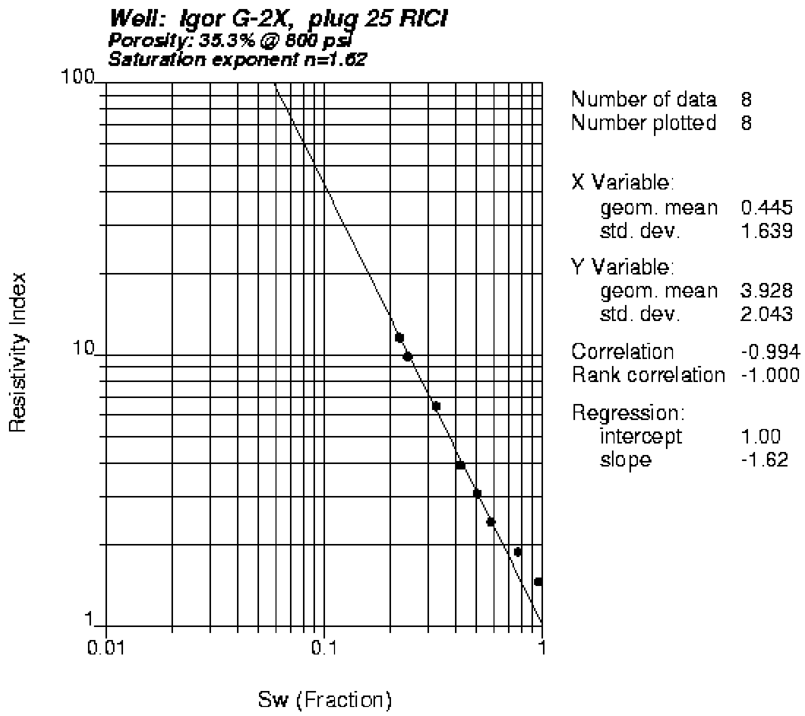
Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**

Plug resistivity data @ 800 psi:

Plug no.: 25
Depth: 6642,00 feet
Formation: Danian

$|Z_0|$, ohm : 40,58

Inj. rate, ml/h	S_w, %	$\lvert Z_t \rvert$, ohm	Phase, deg.	RI
60,0	22	468	-1,20	11,53
30,0	24	397	-1,10	9,78
10,0	32,5	261,8	-1,09	6,45
3,0	42	158,4	-1,31	3,90
1,0	50	124,2	-1,46	3,06
0,3	58	97,73	-1,31	2,41
0,1	77	75,93	-1,27	1,87
0,1	96	58,94	-1,18	1,45



Company: Mærsk Olie og Gas A/S **Well: Igor G-2X**

Plug resistivity data @ 800 psi:

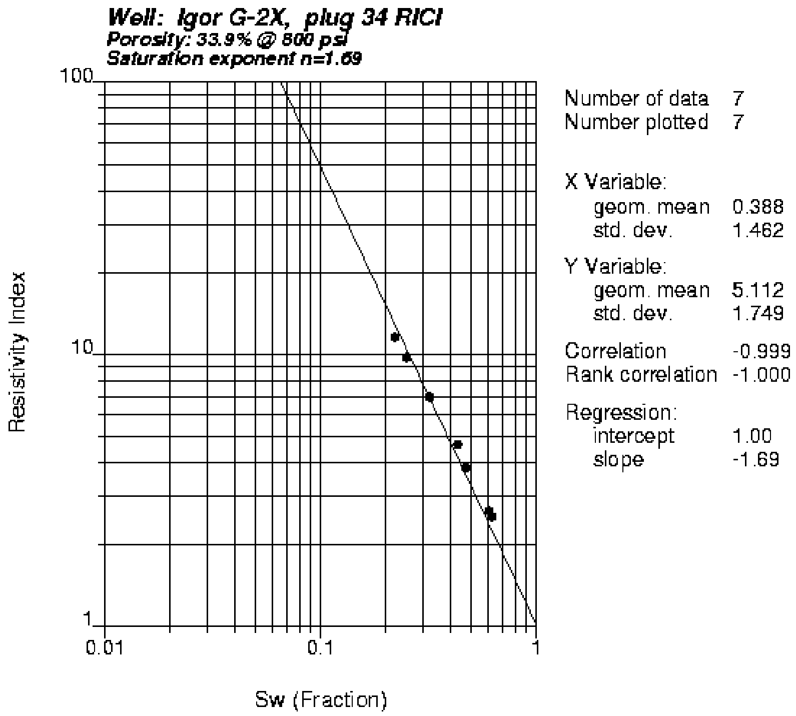
Plug no.: **34**

Depth: **6652,00 feet**

Formation: Danian

$|Z_0|$, ohm : 45,74

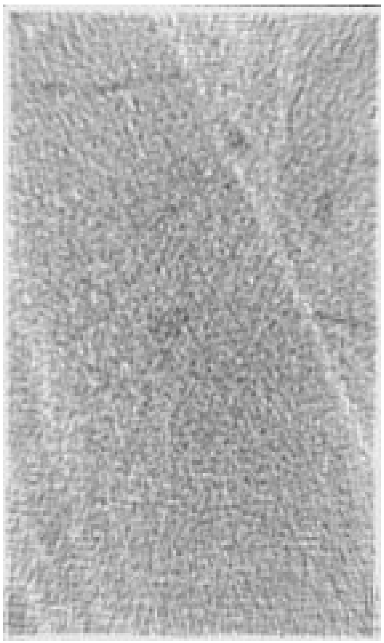
Inj. rate, ml/h	S_w, %	$\lvert Z_t \rvert$, ohm	Phase, deg.	RI
60,0	22	526	-1,70	11,50
30,0	25	443	-1,50	9,69
10,0	32	316,6	-1,47	6,92
3,0	43	212,1	-1,56	4,64
1,0	47	174,3	-1,66	3,81
0,3	60	120,9	-1,54	2,64
0,1	62	115,3	-1,70	2,52



5.3 Plug quality screening

CT-parameters	Algorithm:
standard	
	Voltage: 120 kV mAs: 85 Scan mode: 1s Time: 1s Slice: 2 mm

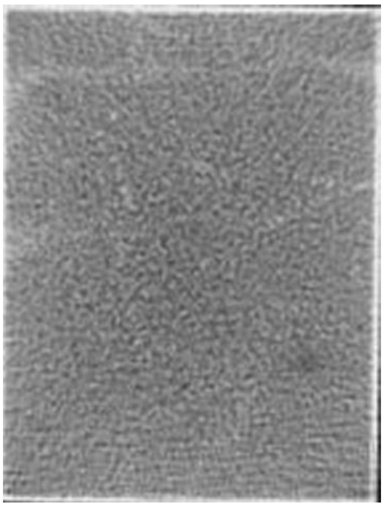
All plugs are 38 mm in diameter and horizontal in orientation.



Plug 2 Rotated 0 deg.
Depth: 6617.33 feet
Selected for: Mercury injection

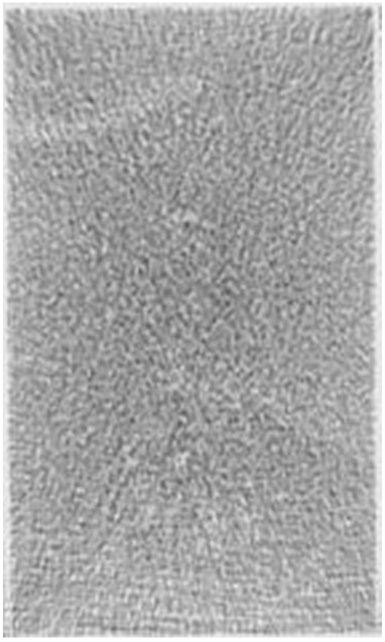
Plug 2 Rotated 90 deg.
Depth: 6617.33 feet
Selected for: Mercury injection

Plug 5 Rotated 0 deg.
Depth: 6620.00 feet
Selected for: Resistivity index

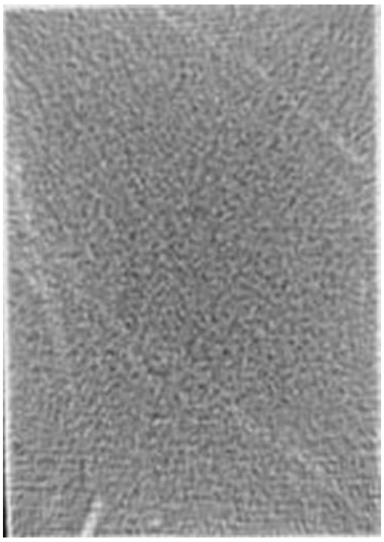


Plug 5 Rotated 90 deg.
Depth: 6620.00 feet
Selected for: Resistivity index

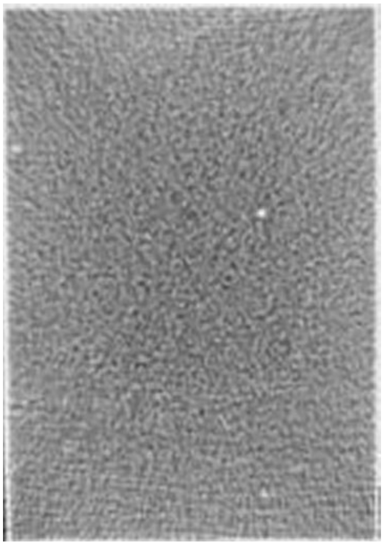
Plug 7 Rotated 0 deg.
Depth: 6622.17 feet
Selected for: Mercury injection



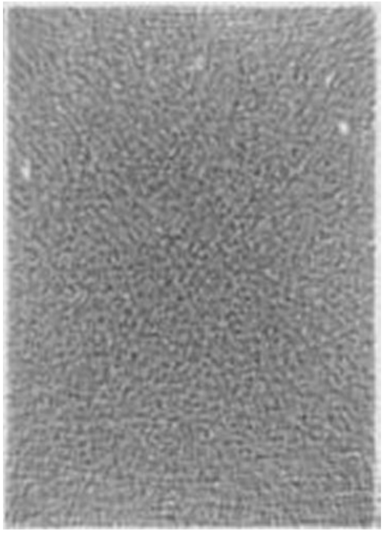
Plug 7 Rotated 90 deg.
Depth: 6622.17 feet
Selected for: Mercury injection



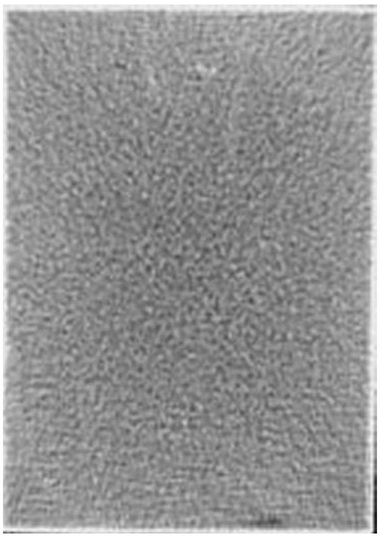
Plug 11 Rotated 0 deg.
Depth: 6626.00 feet
Selected for: Mercury injection



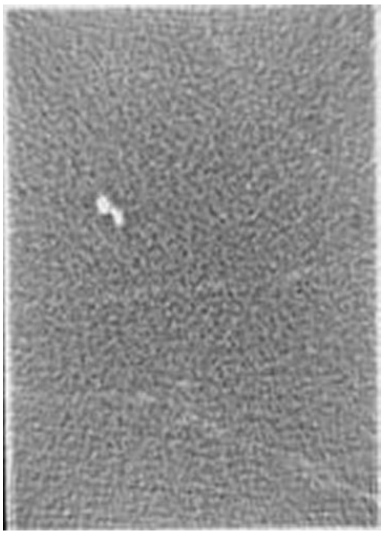
Plug 11 Rotated 90 deg.
Depth: 6626.00 feet
Selected for: Mercury injection



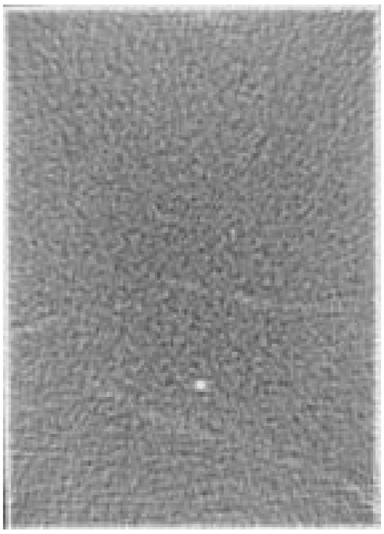
Plug 13 Rotated 0 deg.
Depth: 6628.17 feet
Selected for: Resistivity index



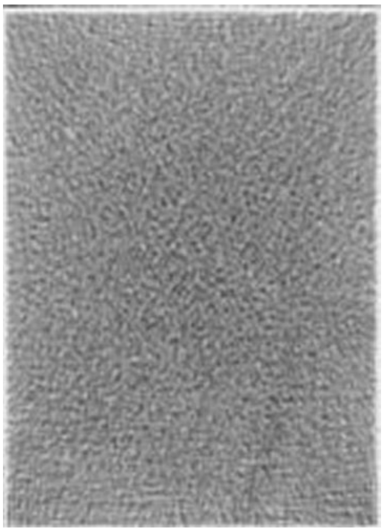
Plug 13 Rotated 90 deg.
Depth: 6628.17 feet
Selected for: Resistivity index



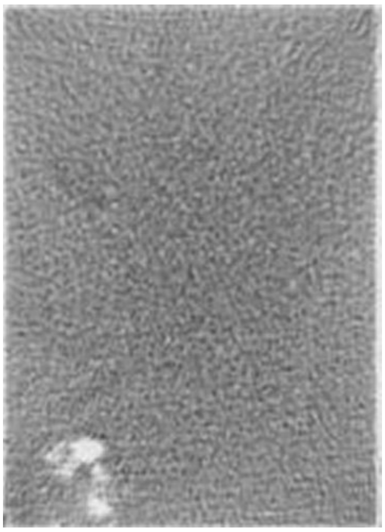
Plug 17 Rotated 0 deg.
Depth: 6633.00 feet
Selected for: Mercury injection



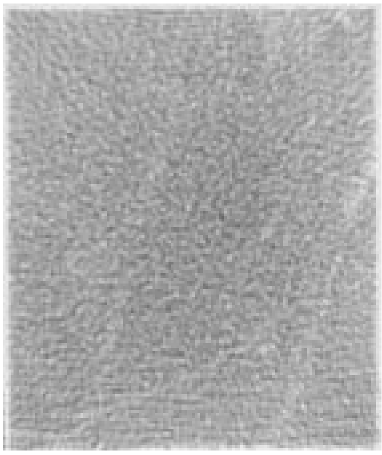
Plug 17 Rotated 90 deg.
Depth: 6633.00 feet
Selected for: Mercury injection



Plug 19 Rotated 0 deg.
Depth: 6634.92 feet
Selected for: Resistivity index

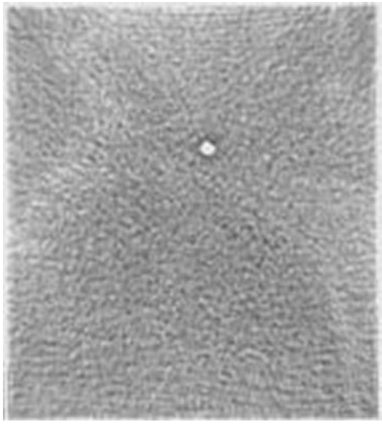


Plug 19 Rotated 90 deg.
Depth: 6634.92 feet
Selected for: Resistivity index

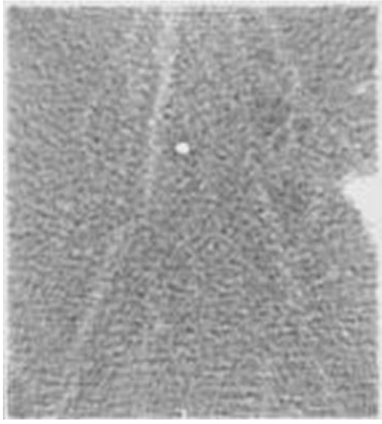


Plug 22 Rotated 0 deg.
Depth: 6639.00 feet
Selected for: Mercury injection

Plug 22 Rotated 90 deg.
Depth: 6639.00 feet
Selected for: Mercury injection



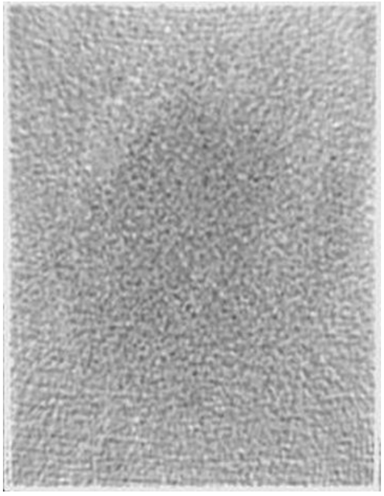
Plug 25 Rotated 0 deg.
Depth: 6642.00 feet
Selected for: Resistivity index



Plug 25 Rotated 90 deg.
Depth: 6642.00 feet
Selected for: Resistivity index

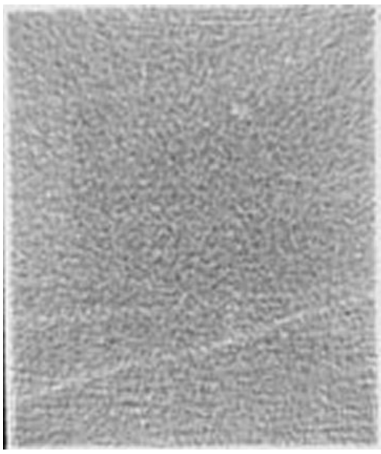
Plug 27 Rotated 0 deg.
Depth: 6644.00 feet
Selected for: Mercury injection

Plug 27 Rotated 90 deg.
Depth: 6644.00 feet
Selected for: Mercury injection

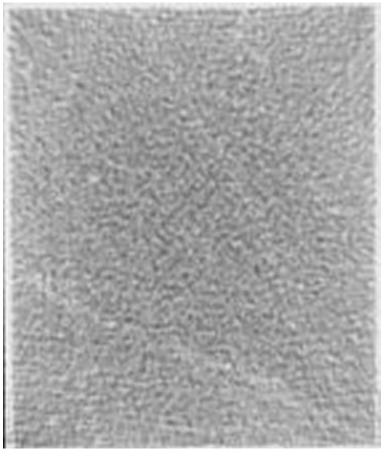


Plug 32 Rotated 0 deg.
Depth: 6650.00 feet
Selected for: Mercury injection

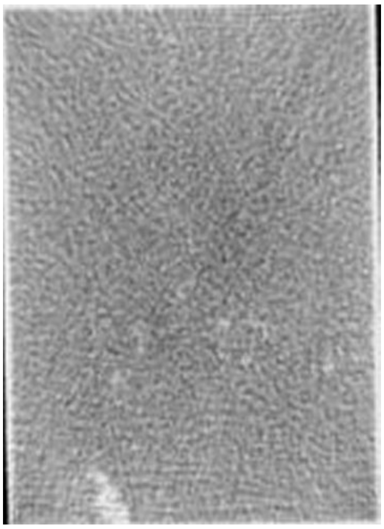
Plug 32 Rotated 90 deg.
Depth: 6650.00 feet
Selected for: Mercury injection



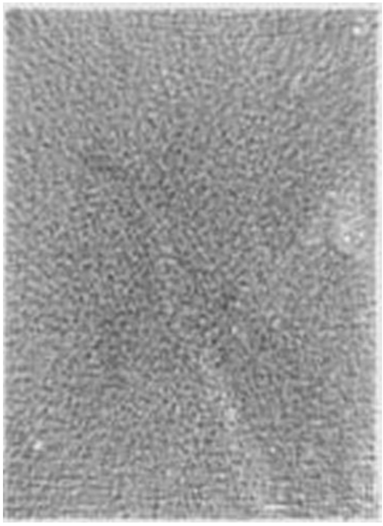
Plug 34 Rotated 0 deg.
Depth: 6652.00 feet
Selected for: Resistivity index



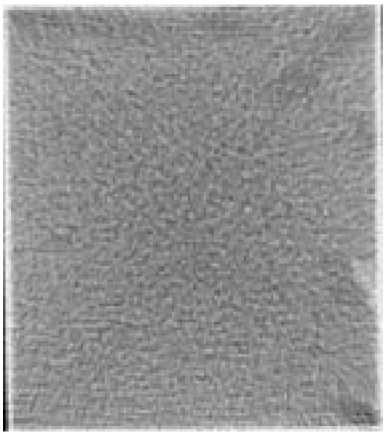
Plug 34 Rotated 90 deg.
Depth: 6652.00 feet
Selected for: Resistivity index



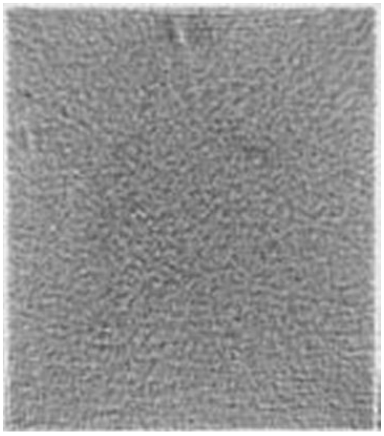
Plug 37 Rotated 0 deg.
Depth: 6654.67 feet
Selected for: Mercury injection



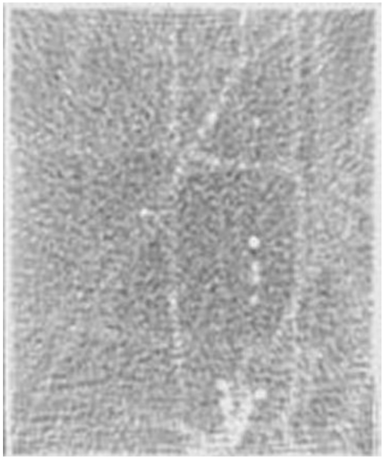
Plug 37 Rotated 90 deg.
Depth: 6654.67 feet
Selected for: Mercury injection



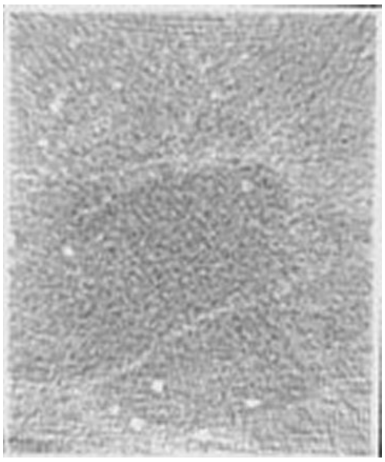
Plug 38 Rotated 0 deg.
Depth: 6655.92 feet
Selected for: Resistivity index



Plug 38 Rotated 90 deg.
Depth: 6655.92 feet
Selected for: Resistivity index

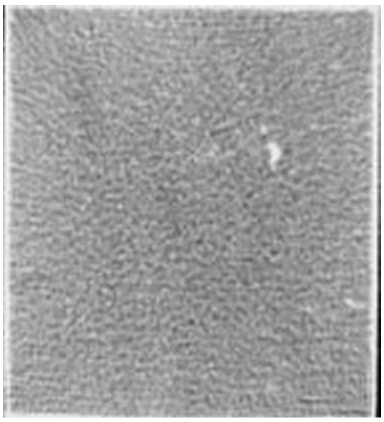


Plug 42 Rotated 0 deg.
Depth: 6661.00 feet
Selected for: Mercury injection

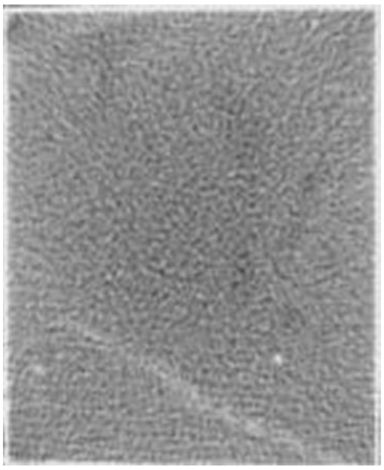


Plug 42 Rotated 90 deg.
Depth: 6661.00 feet
Selected for: Mercury injection

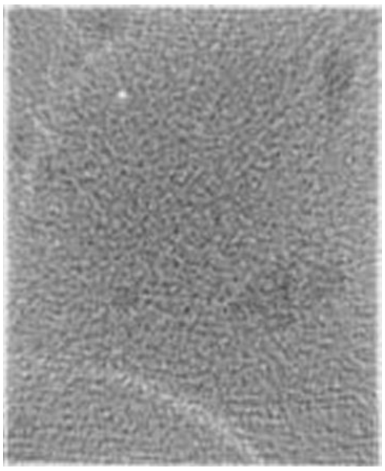
Plug 46 Rotated 0 deg.
Depth: 6665.08 feet
Selected for: Mercury injection



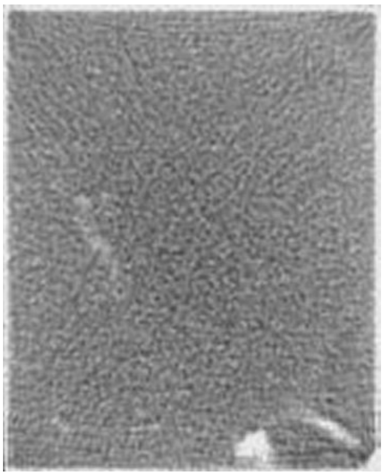
Plug 46 Rotated 90 deg.
Depth: 6665.08 feet
Selected for: Mercury injection



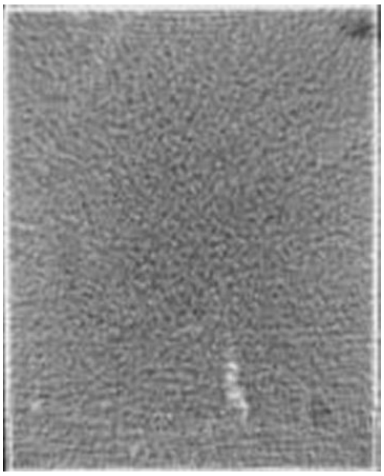
Plug 47 Rotated 0 deg.
Depth: 6666.00 feet
Selected for: Resistivity index



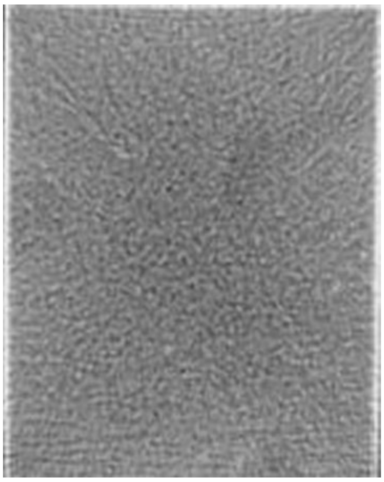
Plug 47 Rotated 90 deg.
Depth: 6666.00 feet
Selected for: Resistivity index



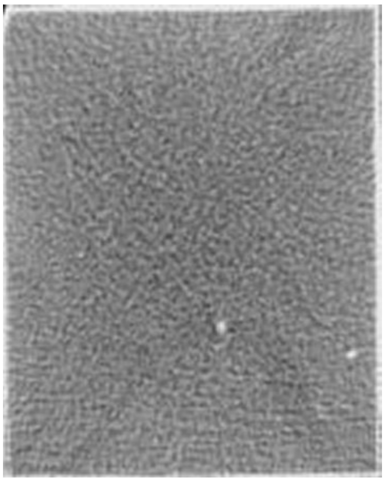
Plug 52 Rotated 0 deg.
Depth: 6672.00 feet
Selected for: Mercury injection



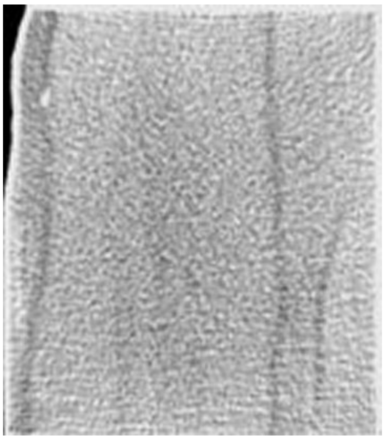
Plug 52 Rotated 90 deg.
Depth: 6672.00 feet
Selected for: Mercury injection



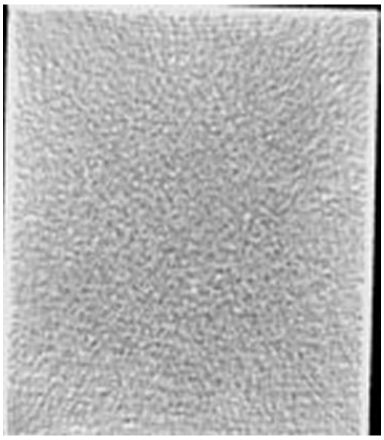
Plug 53 Rotated 0 deg.
Depth: 6672.92 feet
Selected for: Resistivity index



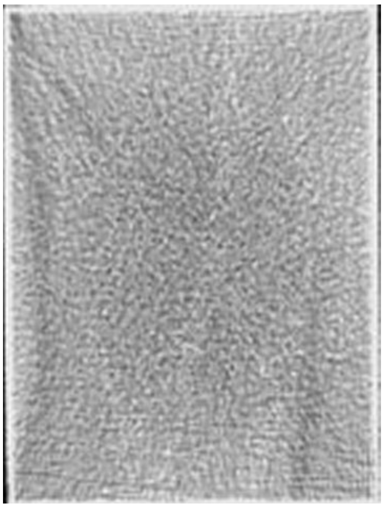
Plug 53 Rotated 90 deg.
Depth: 6672.92 feet
Selected for: Resistivity index

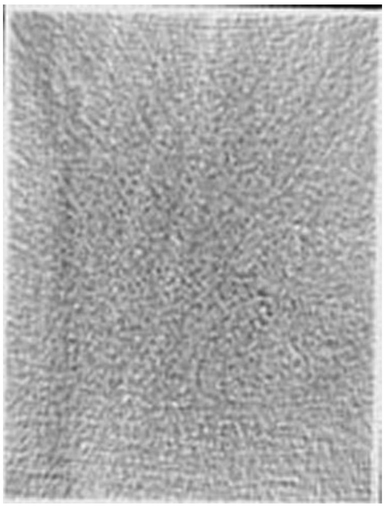


Plug 57 Rotated 0 deg.
Depth: 6788.25 feet
Selected for: Mercury injection



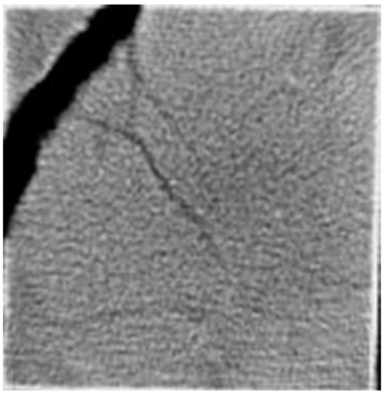
Plug 57 Rotated 90 deg.
Depth: 6788.25 feet
Selected for: Mercury injection





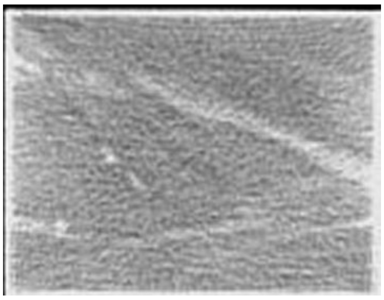
Plug 62 Rotated 0 deg.
Depth: 6793.00 feet
Selected for: Mercury injection

Plug 62 Rotated 90 deg.
Depth: 6793.00 feet
Selected for: Mercury injection

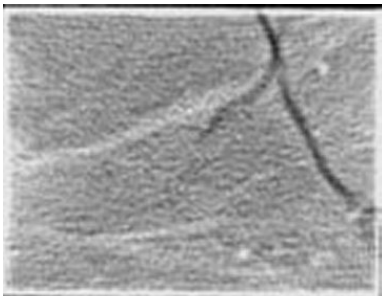


Plug 64 Rotated 0 deg.
Depth: 6795.00 feet
Selected for: Resistivity index

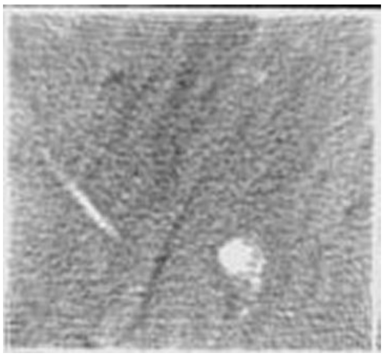
Plug 64 Rotated 90 deg.
Depth: 6795.00 feet
Selected for: Resistivity index



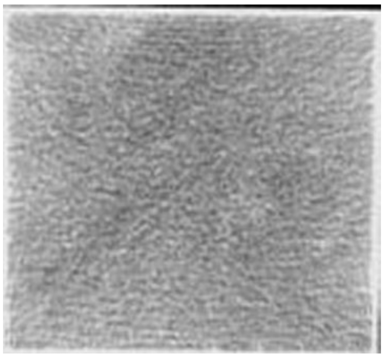
Plug 67 Rotated 0 deg.
Depth: 6798.25 feet
Selected for: Mercury injection



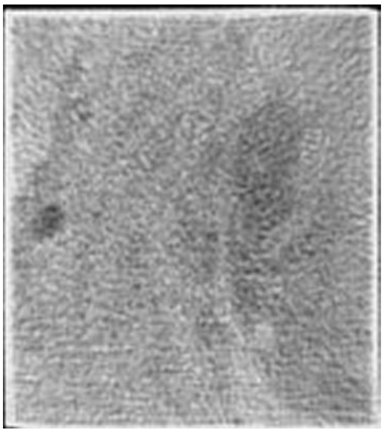
Plug 67 Rotated 90 deg.
Depth: 6798.25 feet
Selected for: Mercury injection



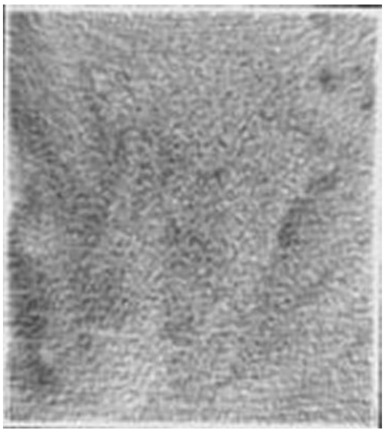
Plug 72 Rotated 0 deg.
Depth: 6804.25 feet
Selected for: Mercury injection



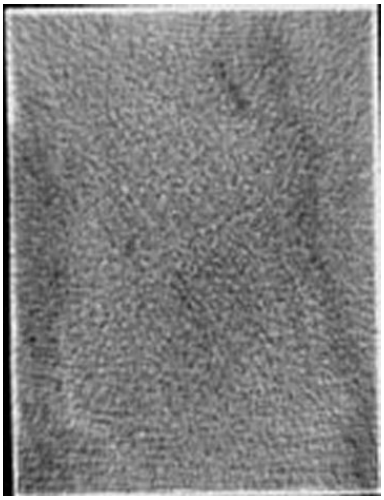
Plug 72 Rotated 90 deg.
Depth: 6804.25 feet
Selected for: Mercury injection



Plug 77 Rotated 0 deg.
Depth: 6809.92 feet
Selected for: Mercury injection

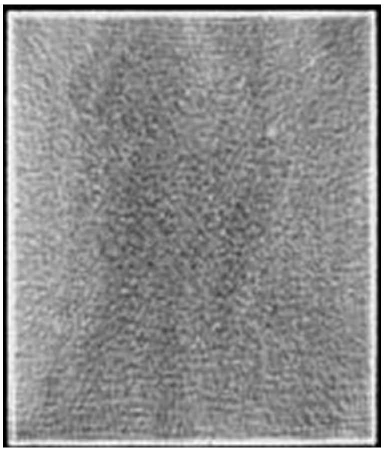


Plug 77 Rotated 90 deg.
Depth: 6809.92 feet
Selected for: Mercury injection

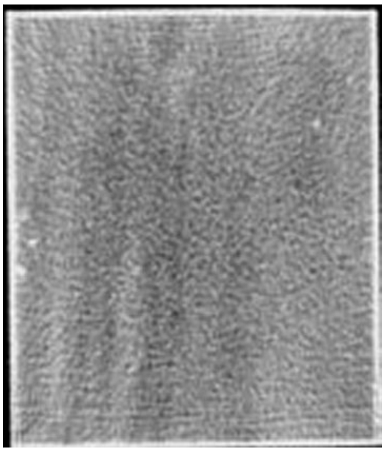


Plug 81 Rotated 0 deg.
Depth: 6813.83 feet
Selected for: Resistivity index

Plug 81 Rotated 90 deg.
Depth: 6813.83 feet
Selected for: Resistivity index

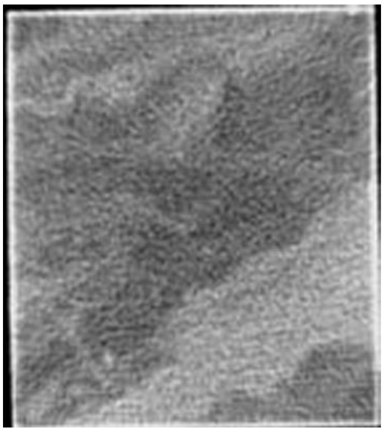


Plug 87 Rotated 0 deg.
Depth: 6820.17 feet
Selected for: Mercury injection

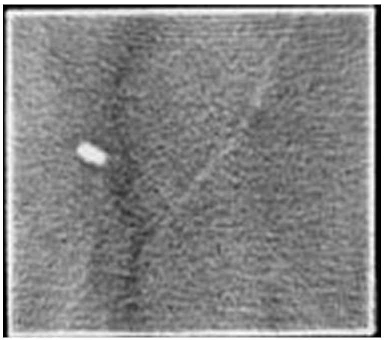


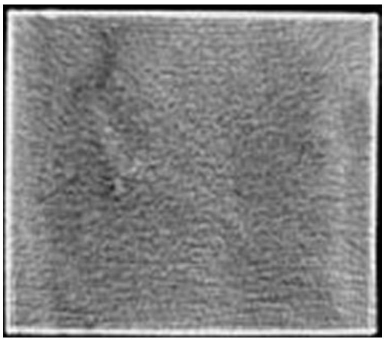
Plug 87 Rotated 90 deg.
Depth: 6820.17 feet
Selected for: Mercury injection

Plug 89 Rotated 0 deg.
Depth: 6822.00 feet
Selected for: Resistivity index



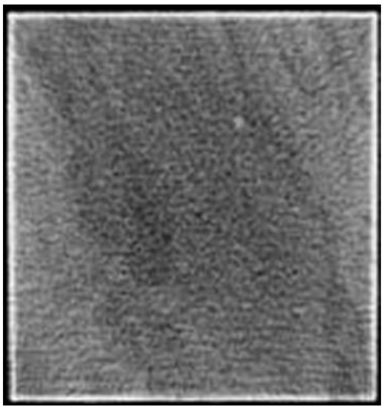
Plug 89 Rotated 90 deg.
Depth: 6822.00 feet
Selected for: Resistivity index

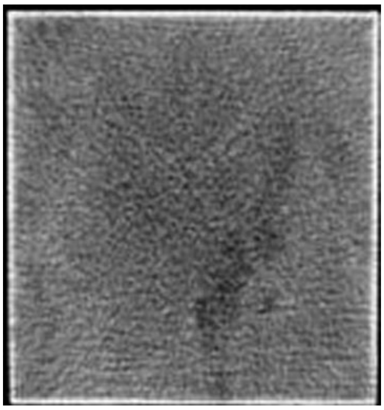




Plug 92 Rotated 0 deg.
Depth: 6824.83 feet
Selected for: Mercury injection

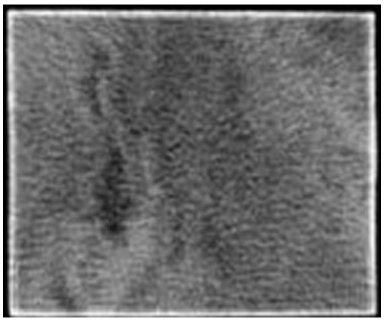
Plug 92 Rotated 90 deg.
Depth: 6824.83 feet
Selected for: Mercury injection



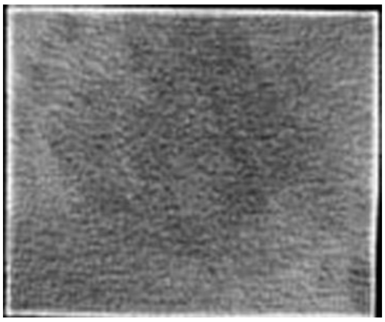


Plug 97 Rotated 0 deg.
Depth: 6830.17 feet
Selected for: Mercury injection

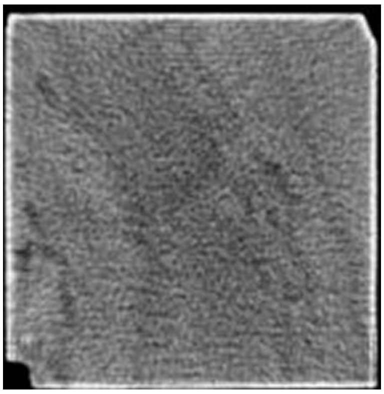
Plug 97 Rotated 90 deg.
Depth: 6830.17 feet
Selected for: Mercury injection



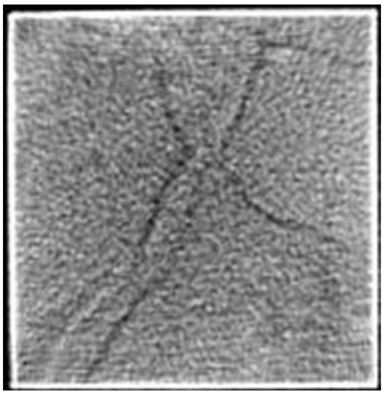
Plug 98 Rotated 0 deg.
Depth: 6831.00 feet
Selected for: Resistivity index



Plug 98 Rotated 90 deg.
Depth: 6831.00 feet
Selected for: Resistivity index



Plug 102 Rotated 0 deg.
Depth: 6836.67 feet
Selected for: Mercury injection



Plug 102 Rotated 90 deg.
Depth: 6836.67 feet
Selected for: Mercury injection

Plug 107 Rotated 0 deg.
Depth: 6842.67 feet
Selected for: Mercury injection

Plug 107 Rotated 90 deg.
Depth: 6842.67 feet
Selected for: Mercury injection

6. References

1. Springer, Niels, Høier, Christian & Stentoft, Niels: Conventional Core Analysis for Mærsk Olie og Gas A/S. Well: Igor G-2X.
   Danmarks og Grønlands Geologiske Undersøgelse Rapport no. 39, 2000.

2. Lyle, W.D & Mills, W.R.: Effect of non-uniform core saturation on laboratory determination of the Archie saturation exponent.
   SPE Formation Evaluation, March 1989, 49-52.

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