DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2005/77

Special core analysis for DONG E&P
Well: NA-7

Compressibility Study

Niels Springer

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

GEUS

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Contents

Enclosure: - Data on CD-ROM

Req. no.: 09201-536
File: NA-7_SCALrep.doc
NA-7P_Cp.xls

1. Introduction

By request of DONG E&P A/S, GEUS Core Laboratory has performed special core analysis on the NA-7P well, Danish North Sea.

The experimental programme was specified in e-mail communications with Messrs. Christian Høier and Morten Stage during September 2005, and a contract ref. R-663/01 was finally signed on September 22, 2005. The following analytical programme has been carried out :

- Fresh / cleaned state plug preparation
- Initial measurement of liquid permeability
- Pore volume compressibility during pressure upload and download cycles
- Fluid saturation and initial porosity determination after test

Preliminary SCAL data have been reported in e-mails and at meetings during the period October to December 2005.

2 Sampling and analytical procedures

A number of preserved plugs from the NA-7 well were forwarded to GEUS Core Laboratory from Core Laboratories UK, ref. table 2.1. The samples consisted of a weakly consolidated (glauconitic) greensand. CT-screening of half of the tested plug samples had been carried out by Core Laboratories UK; these images are found on the attached CD-ROM.

2.1 Plug preparation

An initial screening programme for cleaning procedures was agreed with DONG E&P. Four preserved horizontal plugs, taken as closely spaced sets of two, was either cold flush cleaned in methanol and toluene or flushed with simulated formation brine, table 2.2. A midterm evaluation decided that the remaining samples be tested as fresh state plugs, ref. table 2.1.

2.2 Compressibility test procedure

- Experiment to be completed within one working week during stepwise loading with extended creep during the week-end, and less than one working week during stepwise unloading. Initial step beginning at 10 bar; to be conducted in temperature controlled laboratory @ 25 °C.

- All 8 plugs for SCAL at GEUS:

  Inspect plug and trim if necessary
  Plug dimensions and wet weight
  BV from Hg submersion
  Mount in core holder with ss porous discs in each end and apply 10 bar conf. P

- Fresh state plugs:

  Flush with > 10 PV's of formation brine to clean for drilling mud filtrate and displace gas from plug and core holder assembly
  Measure liq. perm @ 10 bar conf. P
  Connect to electronic balance, shut-in liquid flow and prepare for compressibility experiment to begin on Tuesday/Wednesday morning

- Cleaned state plugs:

  Cold flush cleaning with MeOH-Toluene-MeOH until plug is clean for oil and mud filtrate
  Flush with > 20 PV's of formation brine to displace cleaning fluids and saturate plug with formation brine
  Measure liq. perm @ 10 bar conf. P
  Connect to electronic balance, shut-in liquid flow and prepare for compressibility experiment to begin on Tuesday/Wednesday morning

- Loading of plugs:

  Increase conf. P to next step using 100 bar/h rate
  Record pressure and liquid input / output until next morning
  Increase conf. P to next step as above until final conf. P step
  Final confining P to be applied on Friday and sample left to creep (unattended) until Monday morning
  Uploading steps : 10, 93, 123, 153, 184 bar

Table 2.1. NA-7, list of preserved samples included in the compressibility study. Four additional plugs were prepared as fresh state samples and later delivered to GEO for rock mech testing.

Plug ID	Depth [m]	Plug orientation	Plug preparation	Tested at
6P1	2008.18	H	Fresh state	GEUS
6P2	2008.28	H	Cleaned state	GEUS
6P3	2008.34	H		nd
6P4V	2008.90	V	Fresh state	GEO
14P1	2016.21	H	Fresh state	GEUS
14P2	2016.17	H	Cleaned state	GEUS
14P3	2016.84	H		nd
14P4V	2016.31	V	Fresh state	GEO
A	2020.28	H	Fresh state	GEUS
B	2020.35	V	Fresh state	GEUS
C	2020.50	V	Fresh state	GEO
D	2022.30	V	Fresh state	GEO
E	2022.50	H	Fresh state	GEUS
F	2022.60	V	Fresh state	GEUS

Abbrev.: H = horizontal
V = vertical
nd = not used

- Unloading of plugs:

  Decrease confining P to previous pressure step and let the sample settle until next morning. Decrease conf. P to previous steps as above until initial 10 bar conf. P has been reached.

- CCAL of plugs:

  Cleaned state plugs are cleaned with MeOH and dried while placed in the core holder; then dismantle core holder and transfer sample quantitatively to He-porosimeter sample cup and measure grain volume. Subtract from initial BV to determine initial PV and porosity. Fresh state plugs are transferred quantitatively to Dean Stark extraction, cleaned and measured as above to determine fluid saturation and initial porosity.

2.3 Reservoir pressure data

Info received from DONG:

Core depth: 2015 m MD ~ 1695 TVDSS
Overburden gradient 0.21 Bar/meter
Total OBP = 356 bar.

Pore Pressure initial Pi=185 bar
Pore Pressure Pmin = 100 bar

Initial NOBPi = 356 -185 = 171 bar
Maximum NOBPmax = 356 -100 = 256 bar

Confining Pressure:
Equivalent hydrostatic P initial: CFPinit = 171x0.72 = 123 bar
Equivalent hydrostatic P max: CFPmax = 256x0.72 = 184 bar

Pressure steps applied in compressibility testing: 10, 93, 123, 153 and 184 bar hydrostatic

The midterm evaluation decided to skip the 153 bar confining pressure step for the remaining 4 samples.

Table 2.2. NA-7 simulated formation water analysis supplied by DONG E&P. Measured physical properties appear below.

Subject brine : NA-7P

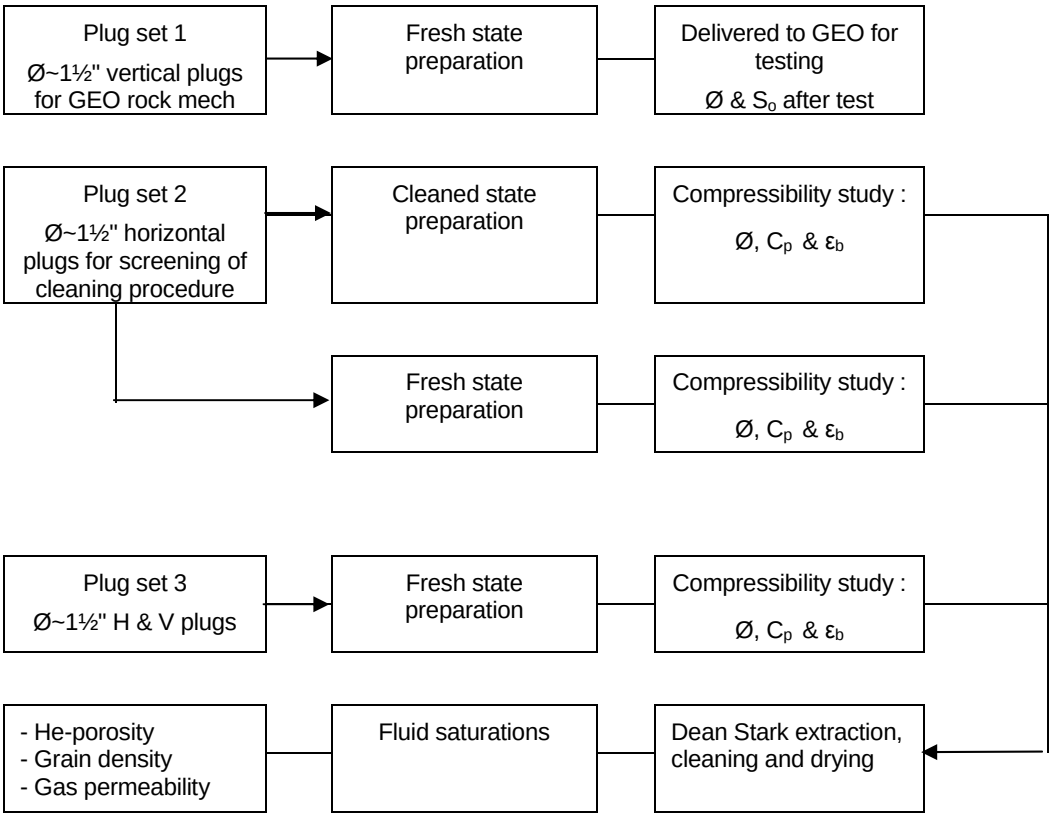
Element	Concentration	Compound	Gram compound per		
	mg/l		1 liter	3 liter	5 liter
Na total	27634				
Na+	27634	NaCl	70.245	210.735	351.22
Na+	0	NaHCO3	0.000	0.000	0.00
K+		KCl	0.000	0.000	0.00
Mg2+	760	MgCl2, 6H2O	6.356	19.067	31.78
Ca2+		CaCl2	0.000	0.000	0.00
Ca2+	6545	CaCl2, 2H2O	24.008	72.024	120.04
Ca2+		CaCl2, 6H2O	0.000	0.000	0.00
Sr2+		SrCl2, 6H2O	0.000	0.000	0.00
Ba2+		BaCl2, 2H2O	0.000	0.000	0.000
Cl-	56410				
HCO3-	0				

TDS: 91349 **mg/l** ~ 1.563 mol/L NaCl eqv.

Comments: Reciepe from DONG per e-mail 05.07.2005

Physical data:	Resistivity Rw : ohmm @ 25.0 C
	Density: 1.059 g/ml @ 25.0 C
	Viscosity: 1.113 cP @ 25.0 C

3 Flow diagram of the analytical procedures



4 Analytical Methods

The compressibility measurements were performed at 25 ± ½ ºC; temperature logs are included with the attached data CD-ROM.

4.1 Overburden measurements

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, constantly monitored using an electronic Mettler balance connected to a PC. The final reading is taken when a stable level has been reached on the balance. The porosity reduction is calculated as the relative decrease in the initial porosity:

$$\emptyset_i = \frac{V_{pi}}{V_{bi}}$$

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

The porosity reduction is then given as:

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

where
$\emptyset_i$ = initial porosity
V_{pi} = initial pore volume
V_{bi} = initial bulk volume
$\emptyset_{i+\Delta P}$ = 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).

Pore volume compressibility: The pore volume compressibility is calculated from the data recorded during the porosity reduction experiment as follows:

$$C_p = \frac{1}{V_p} \cdot \frac{dV_p}{dp_{eff}}$$

where:
C_p = Pore volume compressibility [vol/vol*bar]
V_p = Sample pore volume at a certain effective confining stress (ECS)
dV_p = Incremental change in pore volume resulting from an incremental change in ECS
dp_{eff} = Incremental change in ECS

The relationship dV_p/dp_{eff} is obtained by numerical (or graphical) differentiation of the liquid production curve.

Bulk strain: The bulk volumetric strain is calculated from the porosity reduction data as follows:

$$\varepsilon_b = \frac{\Delta V_p}{V_{bi}} \cdot 100\,\%$$

where ε_b = bulk strain
V_{bi} = initial bulk volume
ΔV_p = change in pore volume due to the increase in confining stress.

The bulk volumetric strain is shown in a diagram of confining stress vs. bulk strain in [%], ref. the diagrams in section 5.2 below.

5 Results

Nomenclature

L – sample length [cm]
D – sample diameter [cm]
A - sample area [cm^2]
BV – bulk volume [cc]
PV – pore volume [cc]
Δ PV– pore volume change [ml]
GD – grain density [g/cc]
V – volume [ml]
Δ V – volume change [ml]
Ø – porosity [pct or frc]
S_w - water saturation [pct or frc]
$_i$ - Subscript for "initial"

C_p = Pore volume compressibility [bar^{-1}]
ε_b - bulk strain [pct]
K_g - permeability to gas [mD]
K_w - permeability to water [mD]
S_o - oil saturation [pct or frc]

5.1 Conventional core analysis data

Table 5.1 below lists the routine core analysis data measured before and after the SCAL test due to most samples being tested in a fresh state condition. Brine permeability K_w @ S_{or} was measured at the initial confining pressure of 10 bar before the compressibility test; gas permeability K_g was measured after test at the usual 27 bar (400 psi) confining pressure. The determination of porosity refers to the plug state before testing as the plug bulk volume was measured by submersion in a mercury bath (Archimedes test). Sample F fractured after extraction and cleaning and could not be measured for gas permeability. The residual oil saturation in the fresh state plugs was determined by Dean Stark extraction after finishing the compressibility experiment.

Table 5.1. CCAL data measured for the plugs used in the NA-7 SCAL study.

Sample ID	Depth [m]	K_g [mD]	Ø [%]	GD [g/cc]	K_w @ S_{or} [mD]	S_{or} [%]
6P1	2008.18	445	36.30	2.761	185	12
6P2	2008.28	546	36.90	2.759	659	0
14P1	2016.21	578	36.80	2.728	275	9
14P2	2016.17	554	37.20	2.733	448	0
A	2020.28	496	37.54	2.746	77	12
B	2020.35	448	37.43	2.738	82	11
E	2022.50	558	37.53	2.753	270	~16
F	2022.60	nd	37.94	2.745	203	~15

5.2 Compressibility data

The liquid expelled during the loading phase was recorded on an analytical balance and data used in calculation of the porosity reduction and pore volume compressibility, ref. the diagrams attached below. It is observed that within the applied hydrostatic stress range the samples behaves as a linear elastic media. However, the unloading data shows that the samples did not return to the initial state during the unloading test period (3-4 days), section 5.4.

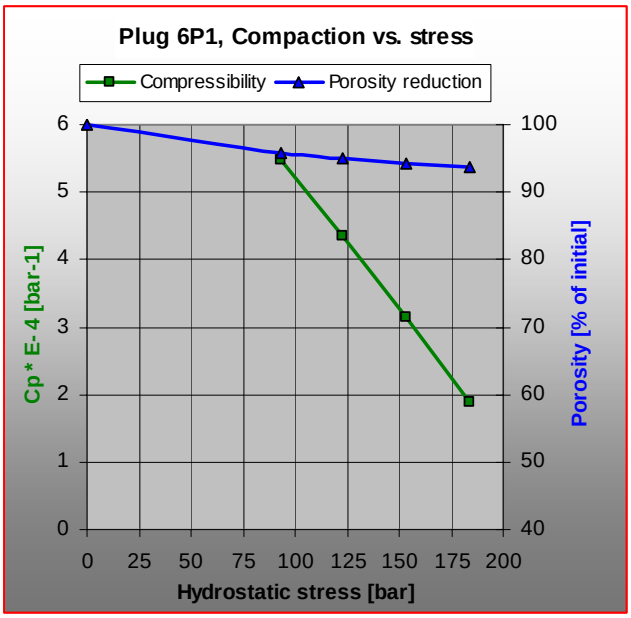
The diagrams also show the recorded pump data. The discrepancy between the balance and pump data is due to the system compressibility and the additional effect of trapped air in the core holder that could not be vented completely.

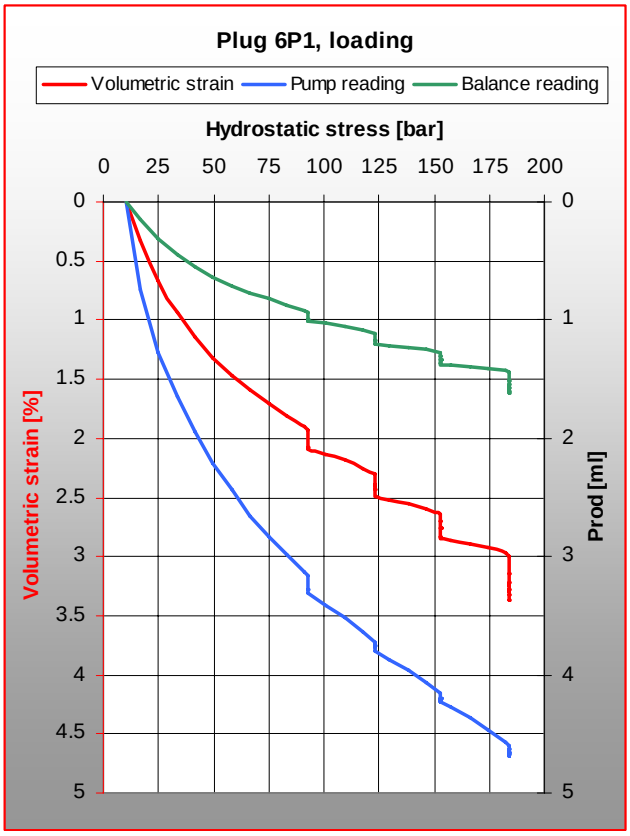
Sample 6P2 had a surprisingly large compressibility. The liquid production curve, section 5.4, indicated that a leak may have been present during this experiment. A blind experiment conducted later with massive steel plugs showed that one rubber sleeve used in the experiments was defect. Data for sample 6P2 was then corrected according to the blind experiment and the general observation that unloading data for the other samples showed a linear or gently falling trend in the range 184 > 93 bar confining stress. Further details of the blind experiments can be found in the attached Excel spreadsheet.

Subject: Compressibility measurements — **Company: DONG E&P A/S**
Plug data at @ 25 °C — **Well: NA-7**

Plug no :	**6P1**
Depth [m] :	**2008.18**
He-∅ [%] :	**36.30**
K_g [mD] :	**445**

Conf. stress	Reduction in		C_p	ε_b
[bar]	He-∅ [%]	% of initial	[bar^{-1}]	[%]
0	36.30	100.0		
93	34.74	95.7	5.48E-04	2.1
123	34.47	95.0	4.34E-04	2.5
153	34.23	94.3	3.15E-04	2.9
184	33.99	93.6	1.88E-04	3.4

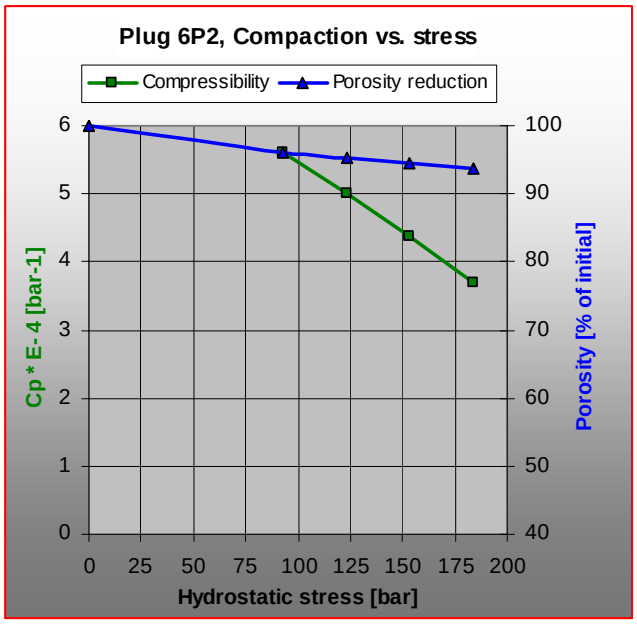


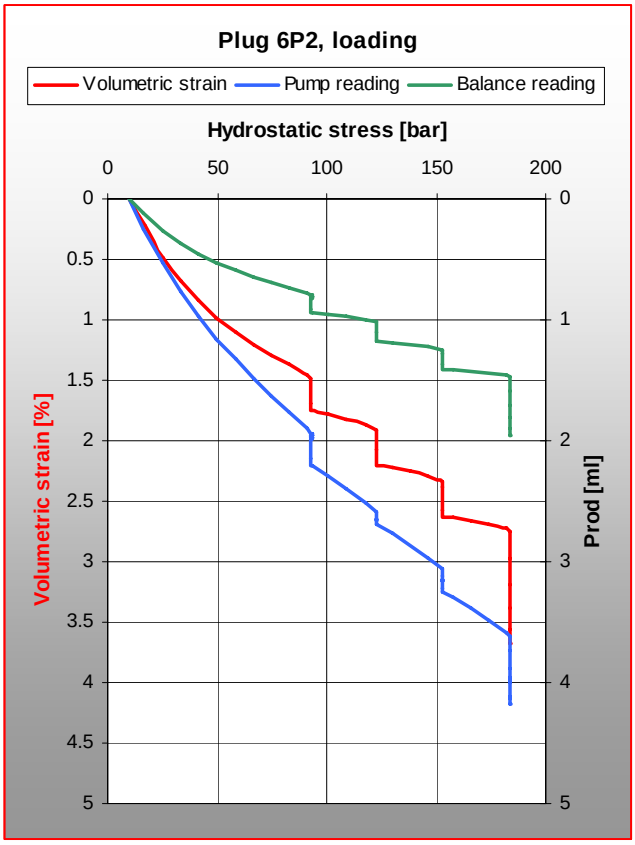


Subject: Compressibility measurements **Company: DONG E&P A/S**
Plug data at @ 25 °C **Well: NA-7**

Plug no : **6P2**
Depth [m] : **2008.28**
He-∅ [%] : **36.90**
K_g [mD] : **546**

Conf. stress	Reduction in		C_p	ε_b
[bar]	He-∅ [%]	% of initial	[bar^{-1}]	[%]
0	36.90	100.0		
93	35.47	96.1	5.60E-04	1.8
123	35.17	95.3	5.00E-04	2.2
153	34.89	94.5	4.37E-04	2.6
184	34.53	93.6	3.69E-04	3.7

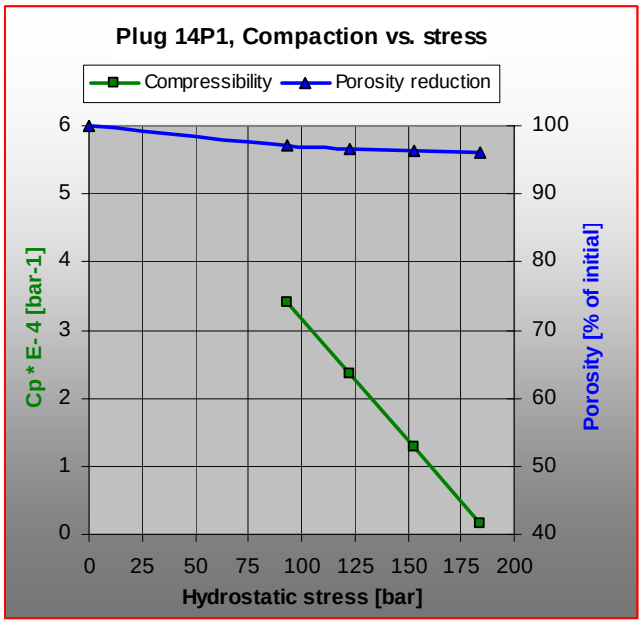


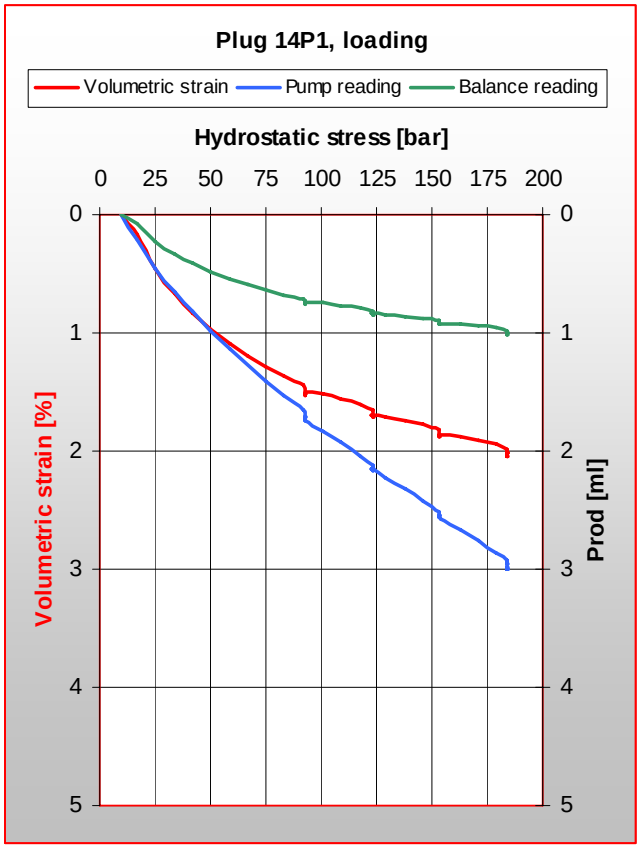


Subject: Compressibility measurements **Company: DONG E&P A/S**
Plug data at @ 25 °C **Well: NA-7**

Plug no :	**14P1**
Depth [m] :	**2016.21**
He-∅ [%] :	**36.80**
K_g [mD] :	**578**

Conf. stress	Reduction in		C_p	ε_b
[bar]	He-∅ [%]	% of initial	[bar^{-1}]	[%]
0	36.80	100.0		
93	35.70	97.0	3.40E-04	1.5
123	35.57	96.7	2.35E-04	1.7
153	35.46	96.3	1.28E-04	1.9
184	35.35	96.1	1.53E-05	2

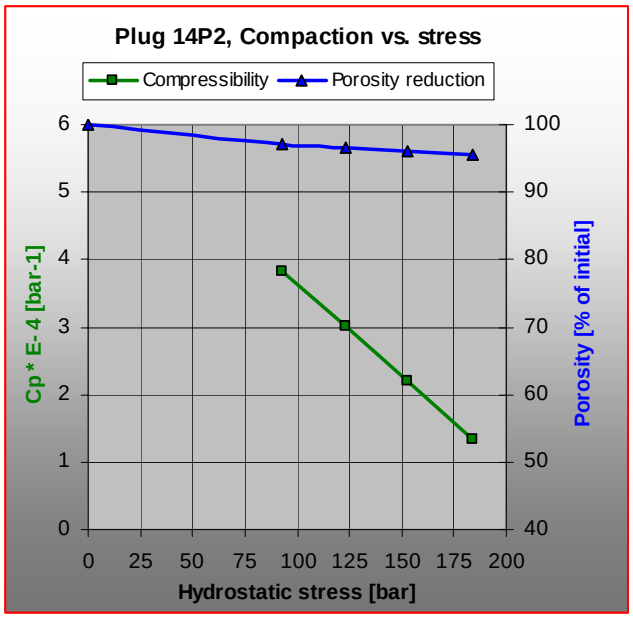


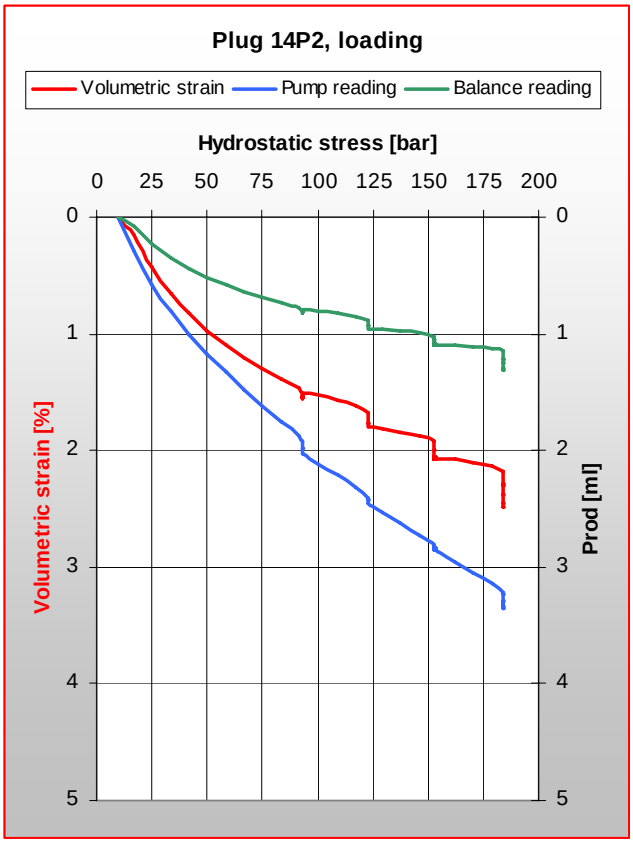


Subject: Compressibility measurements **Company: DONG E&P A/S**
Plug data at @ 25 °C **Well: NA-7**

Plug no : **14P2**
Depth [m] : **2016.17**
He-∅ [%] : **37.20**
K_g [mD] : **554**

Conf. stress	Reduction in		C_p	ε_b
[bar]	He-∅ [%]	% of initial	[bar^{-1}]	[%]
0	37.20	100.0		
93	36.10	97.0	3.82E-04	1.5
123	35.91	96.5	3.02E-04	1.8
153	35.73	96.0	2.20E-04	2.1
184	35.58	95.6	1.34E-04	2.5

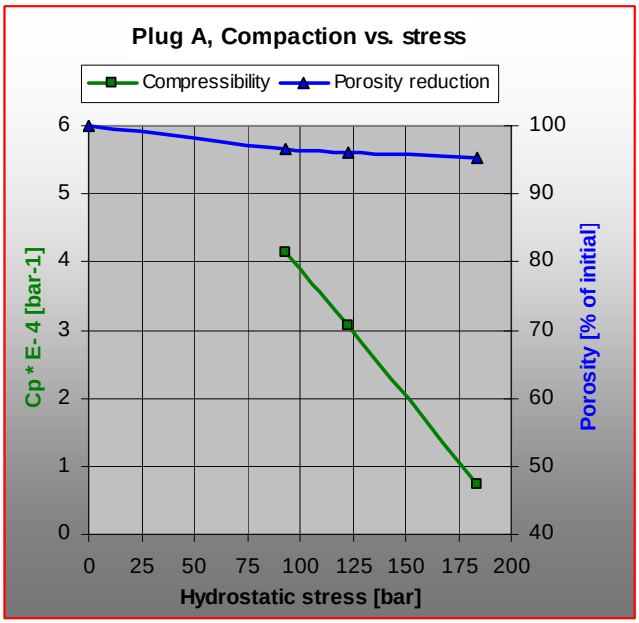


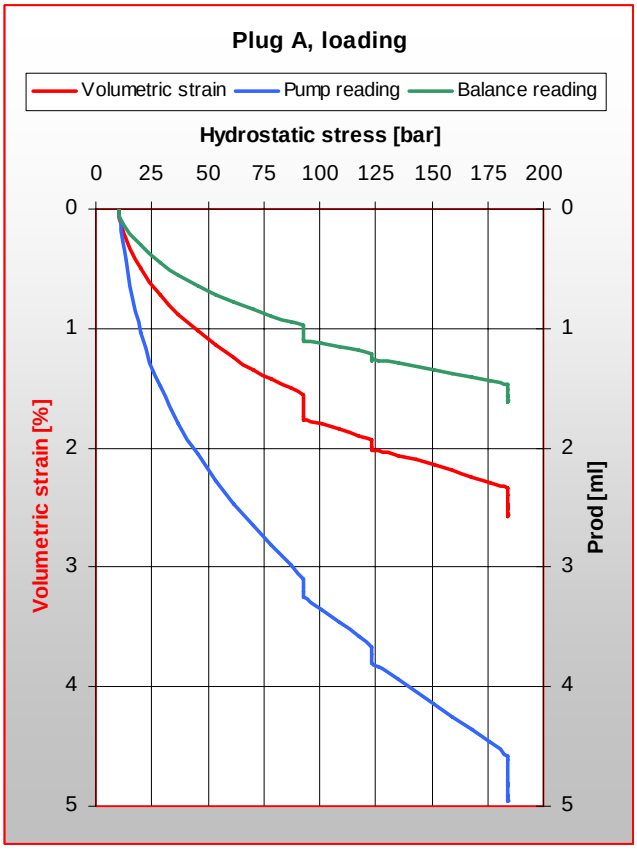


Subject: Compressibility measurements **Company: DONG E&P A/S**
Plug data at @ 25 °C **Well: NA-7**

Plug no : **A**
Depth [m] : **2020.28**
He-∅ [%] : **37.54**
K_g [mD] : **496**

Conf. stress	Reduction in		C_p	ε_b
[bar]	He-∅ [%]	% of initial	[bar^{-1}]	[%]
0	37.54	100.0		
93	36.27	96.6	4.15E-04	1.7
123	36.09	96.1	3.06E-04	2.0
153	#I/T	#I/T	#I/T	nd
184	35.78	95.3	7.44E-05	2.6

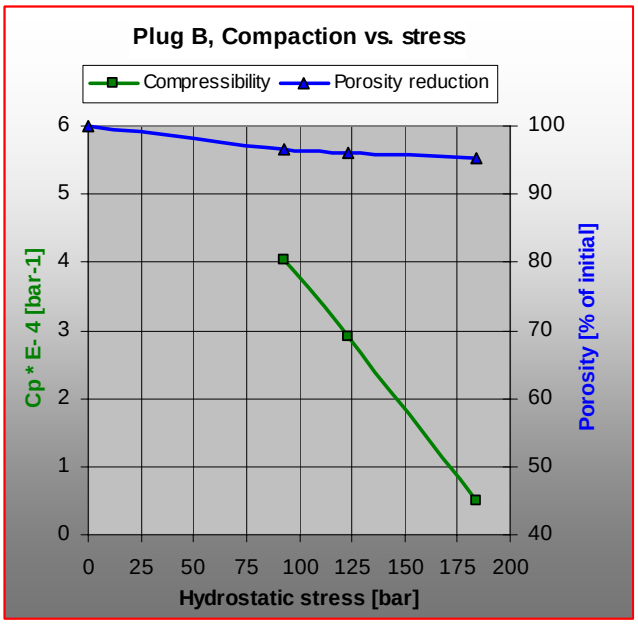


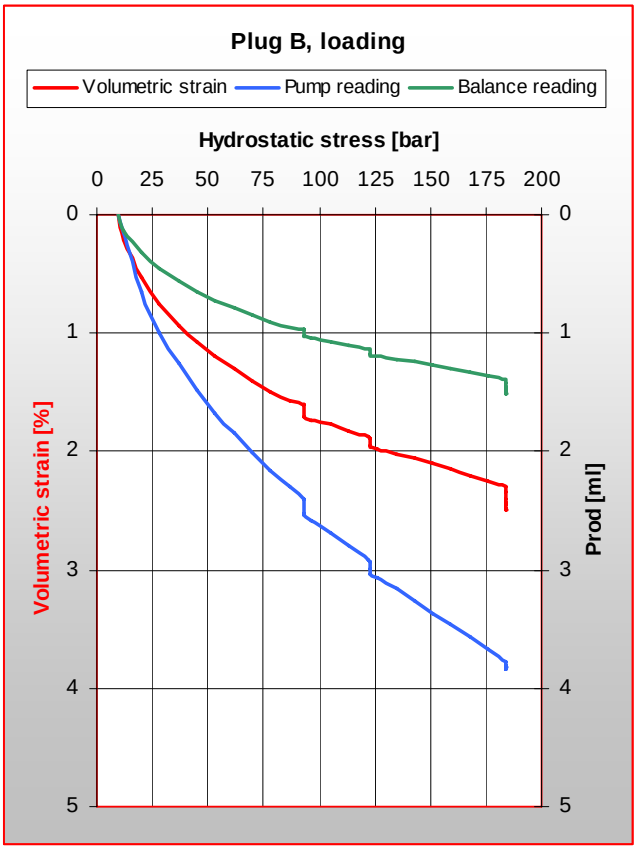


Subject: Compressibility measurements **Company: DONG E&P A/S**
Plug data at @ 25 °C **Well: NA-7**

Plug no : **B**
Depth [m] : **2020.35**
He-∅ [%] : **37.43**
Kg [mD] : **448**

Conf. stress	Reduction in		C_p	ε_b
[bar]	He-∅ [%]	% of initial	[bar^{-1}]	[%]
0	37.43	100.0		
93	36.16	96.6	4.05E-04	1.7
123	35.99	96.2	2.90E-04	2.0
153	#I/T	#I/T	#I/T	nd
184	35.71	95.4	4.92E-05	2.5

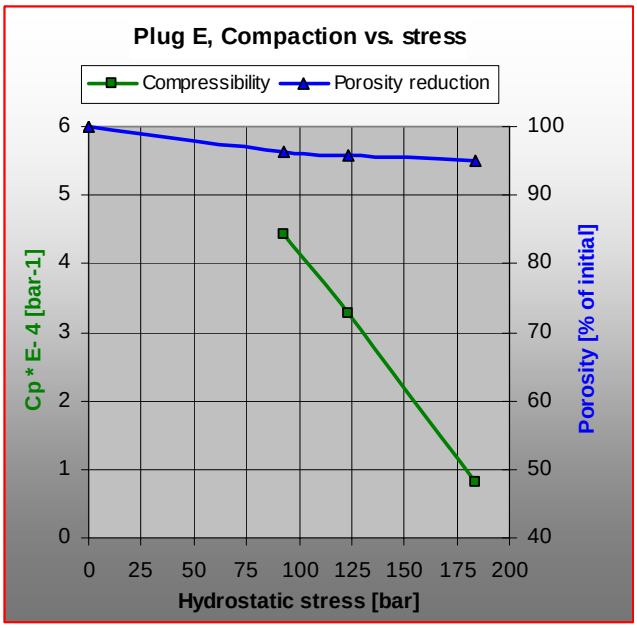


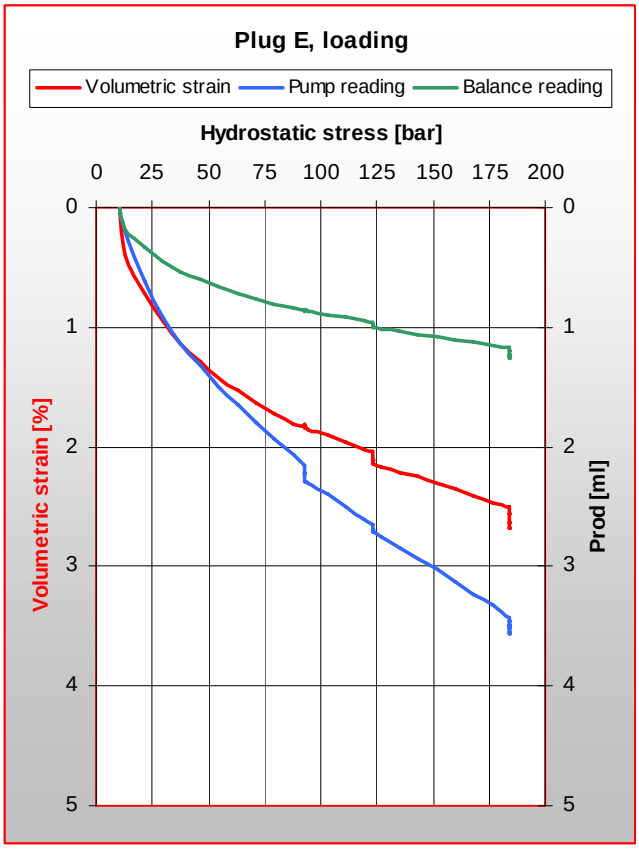


Subject: Compressibility measurements **Company: DONG E&P A/S**
Plug data at @ 25 °C **Well: NA-7**

Plug no :	**E**
Depth [m] :	**2022.50**
He-∅ [%] :	**37.53**
K_g [mD] :	**558**

Conf. stress	Reduction in		C_p	ε_b
[bar]	He-∅ [%]	% of initial	[bar^{-1}]	[%]
0	37.53	100.0		
93	36.19	96.4	4.42E-04	1.8
123	35.98	95.9	3.26E-04	2.1
153	#I/T	#I/T	#I/T	nd
184	35.66	95.0	8.24E-05	2.7

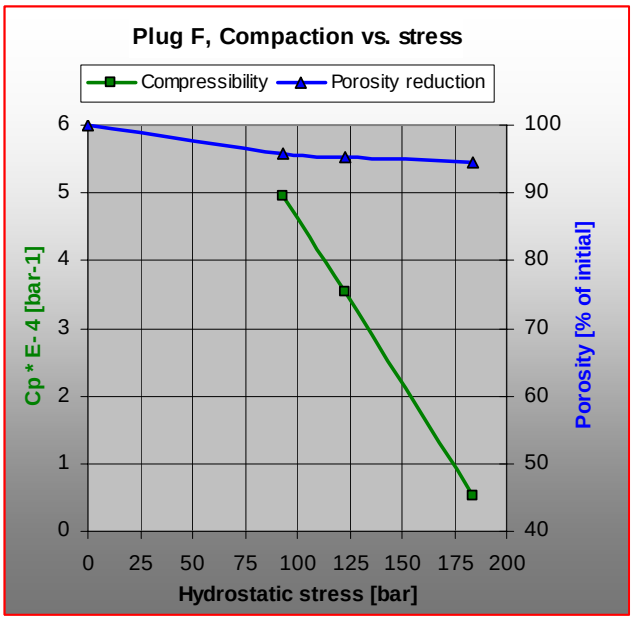


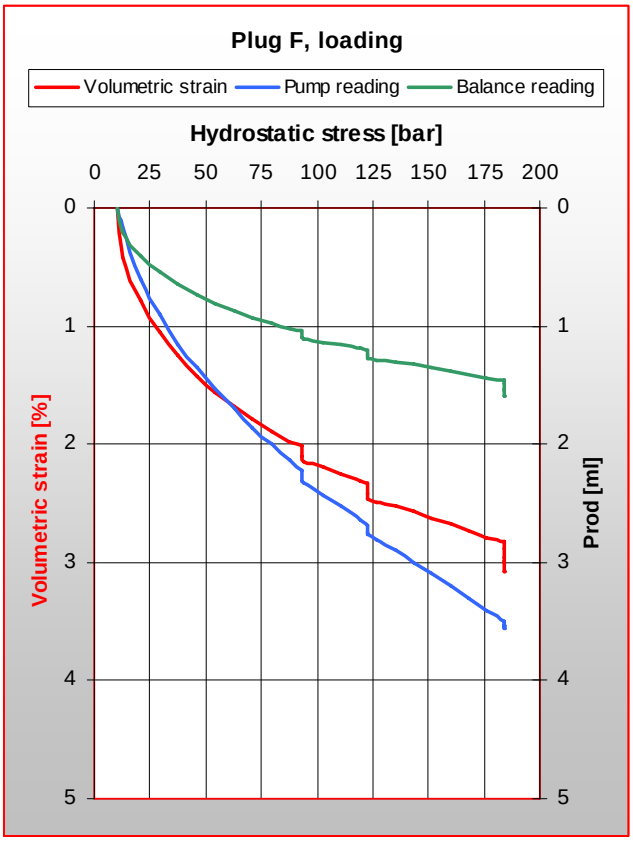


Subject: Compressibility measurements **Company: DONG E&P A/S**
Plug data at @ 25 °C **Well: NA-7**

Plug no : **F**
Depth [m] : **2022.60**
He-∅ [%] : **37.94**
K_g [mD] : **nd**

Conf. stress	Reduction in		C_p	ε_b
[bar]	He-∅ [%]	% of initial	[bar^{-1}]	[%]
0	37.94	100.0		
93	36.38	95.9	4.96E-04	2.1
123	36.16	95.3	3.54E-04	2.5
153	#I/T	#I/T	#I/T	nd
184	35.82	94.4	5.14E-05	3.1

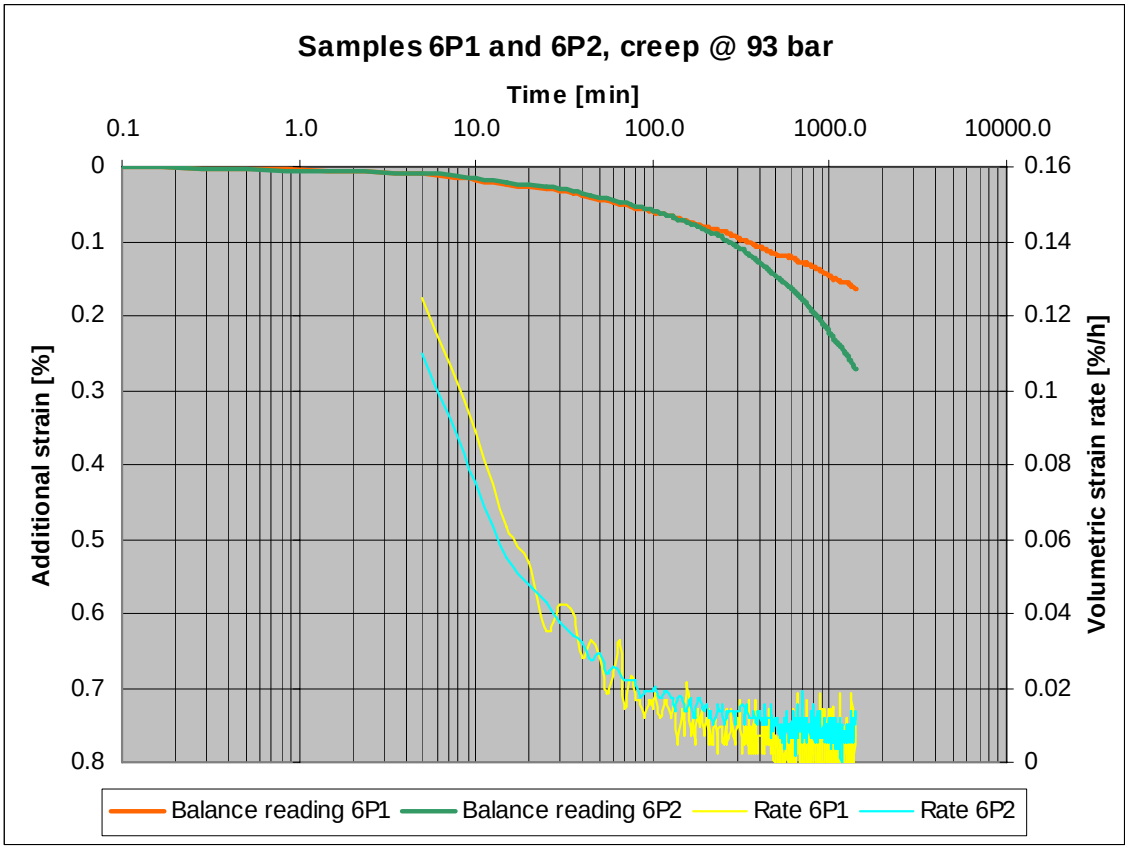


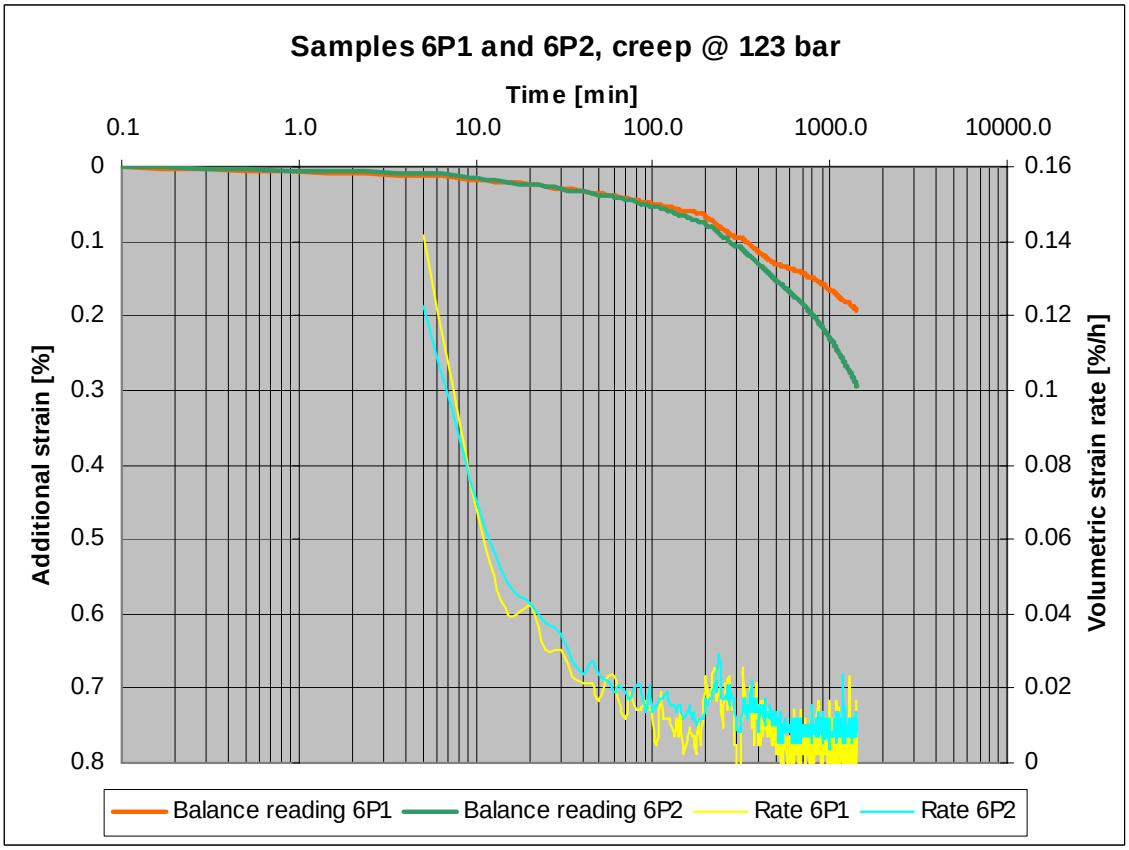


5.3 Creep data

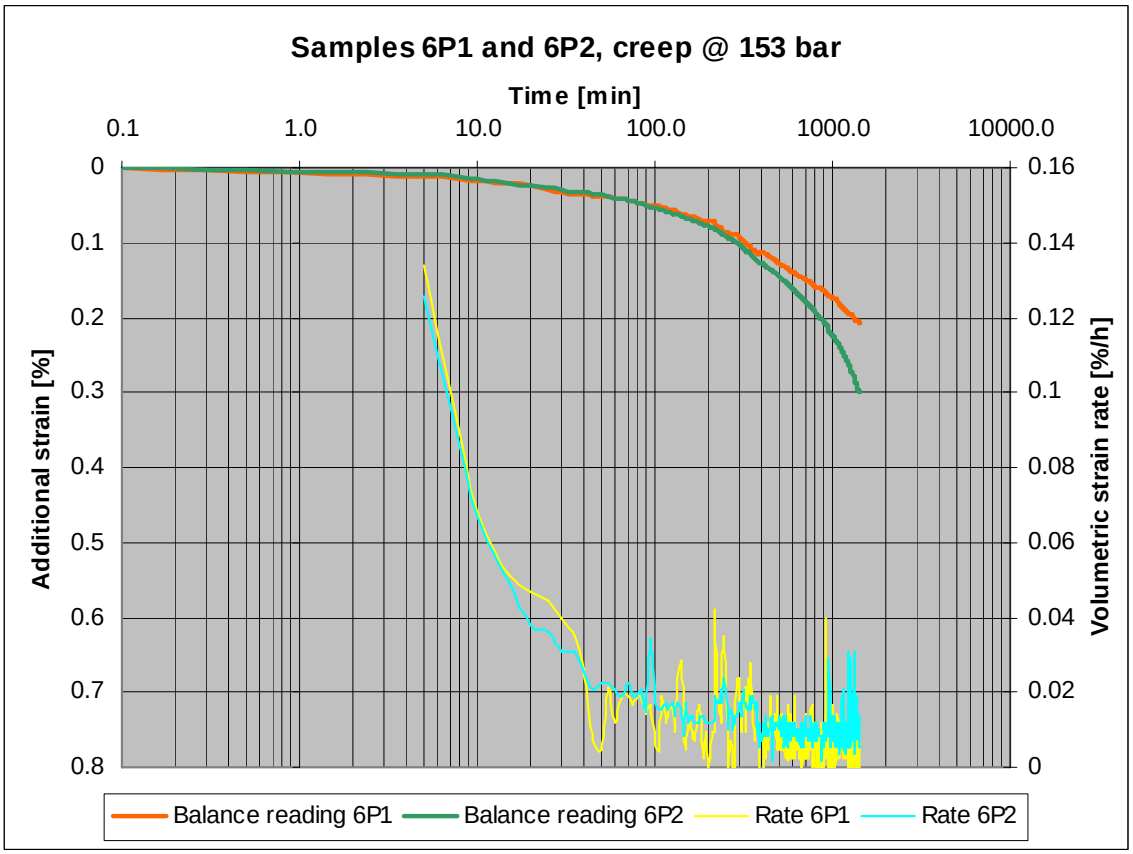
After mounting and flushing the test sample in the core holder at 10 bar confining stress, the sample was left to settle for 1-2 days before initiating the compressibility experiment. At each pressure step above 10 bar the sample was left to consolidate and creep for close to 24 hours. Time curves for each pressure step and sample pair are given below.

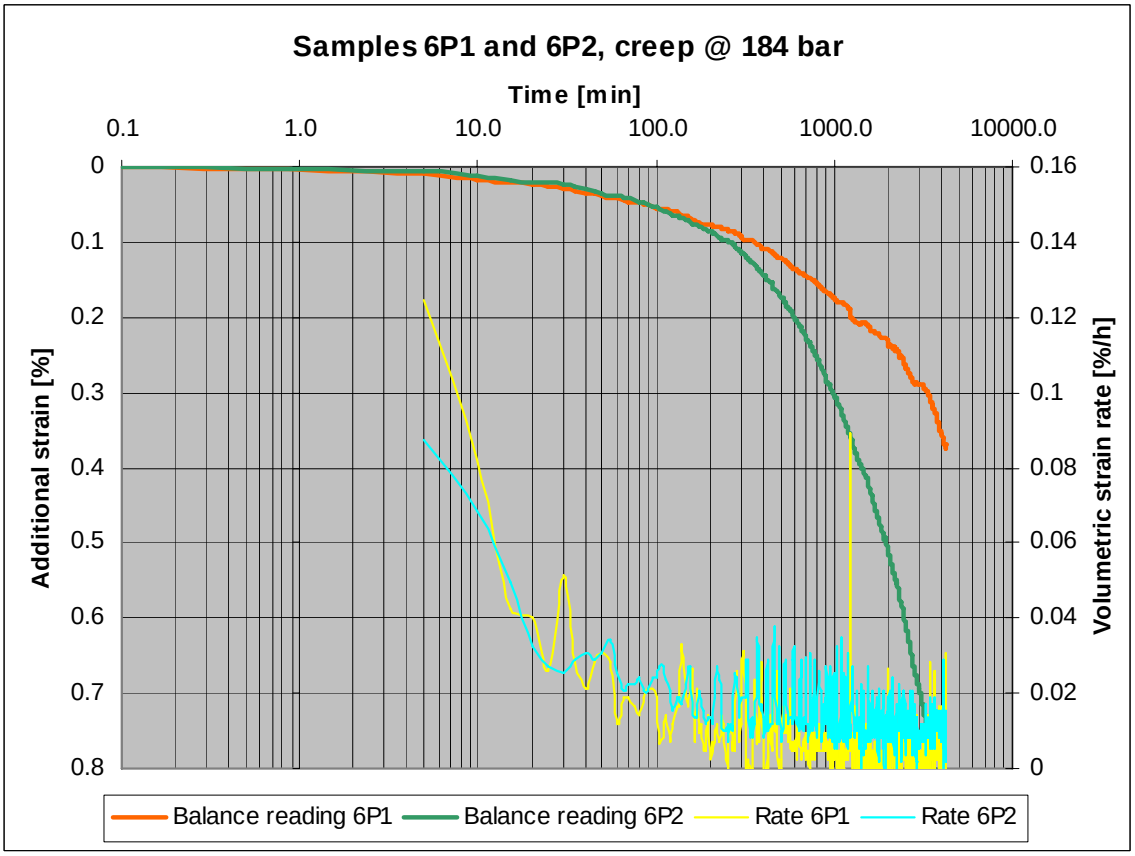
Samples 6P1 and 6P2:



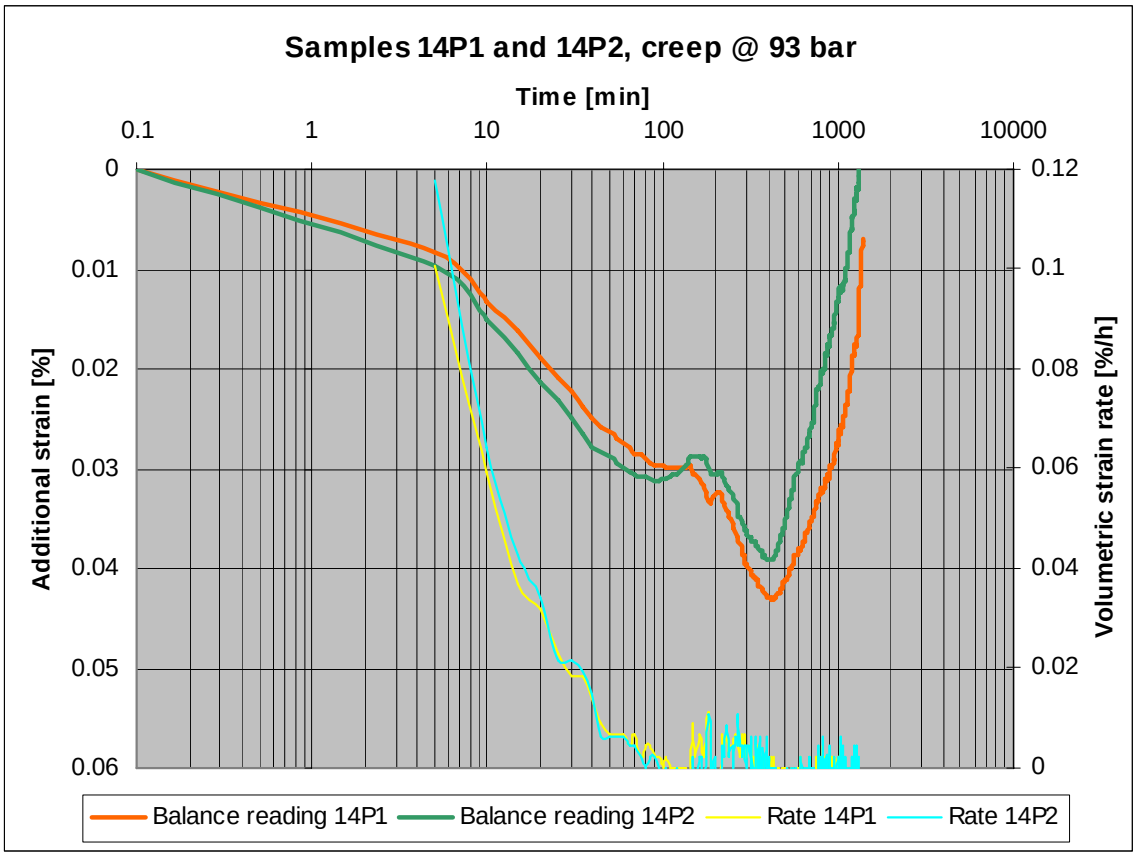


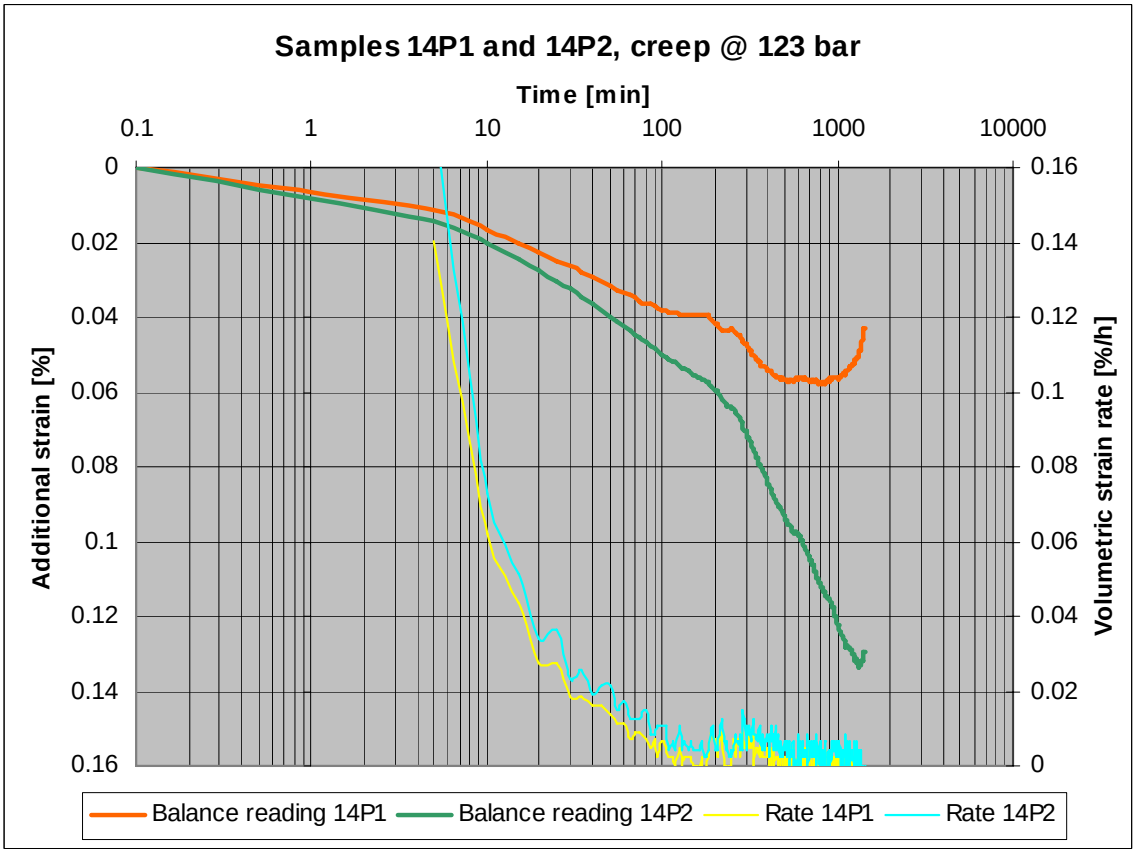
Samples 6P1 and 6P2 cont.:



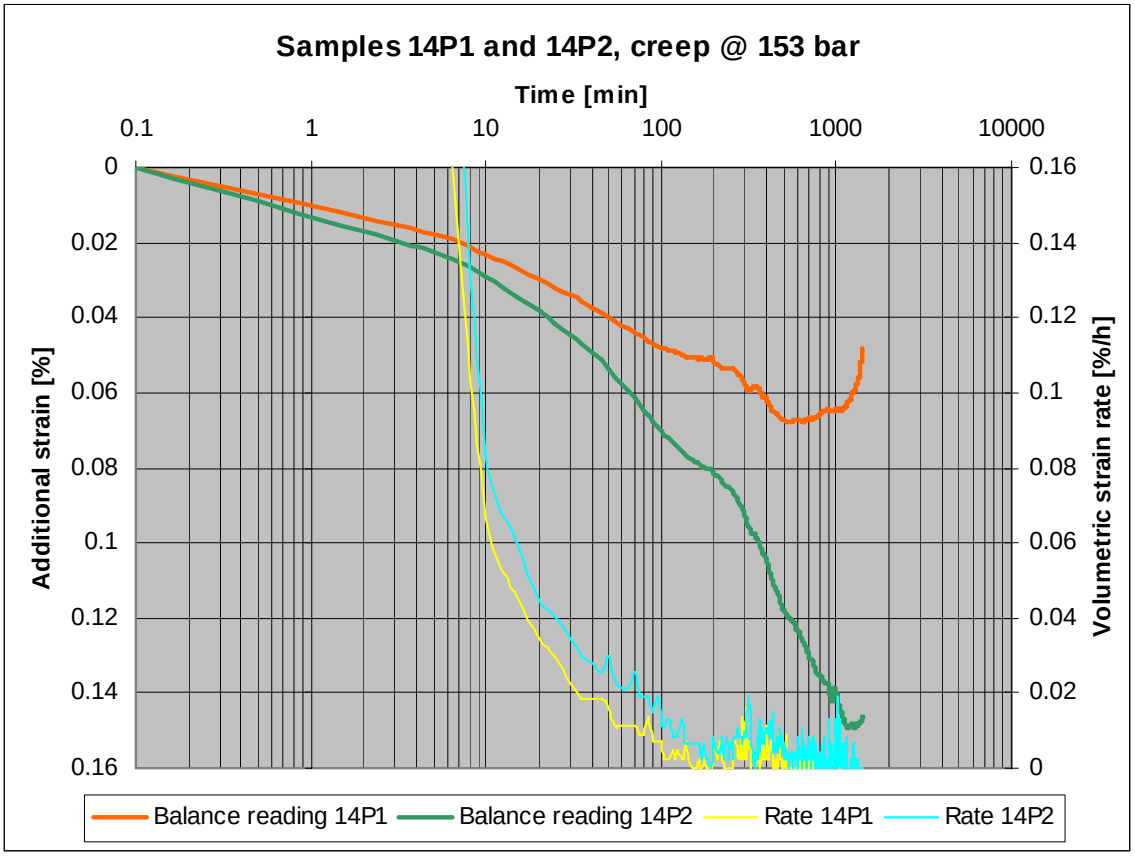


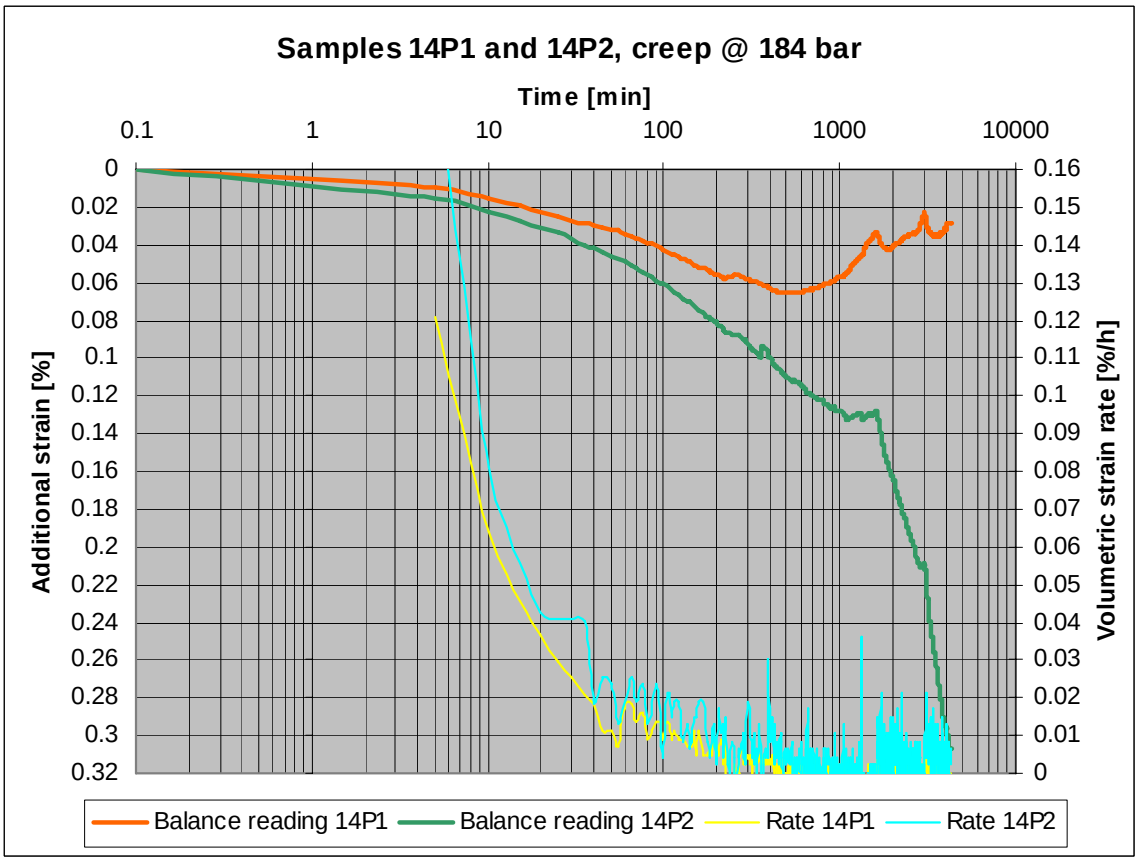
Samples 14P1 and 14P2:



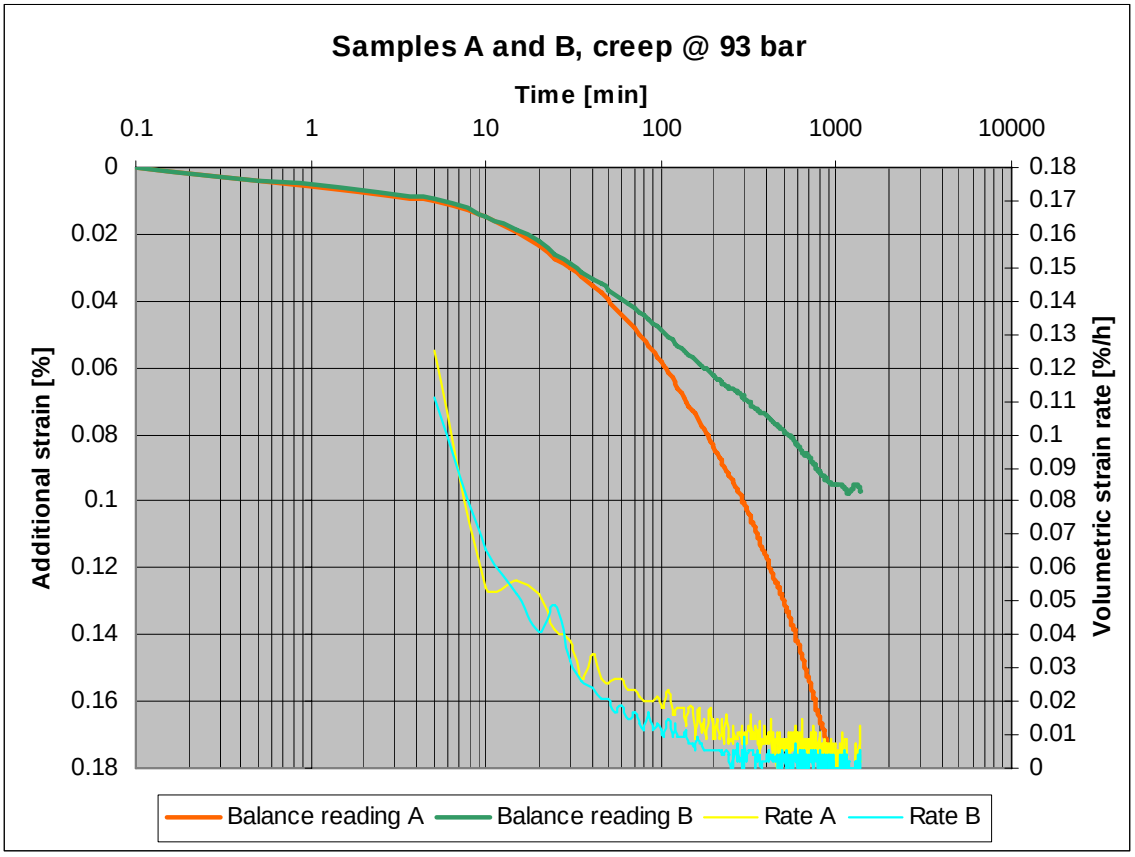


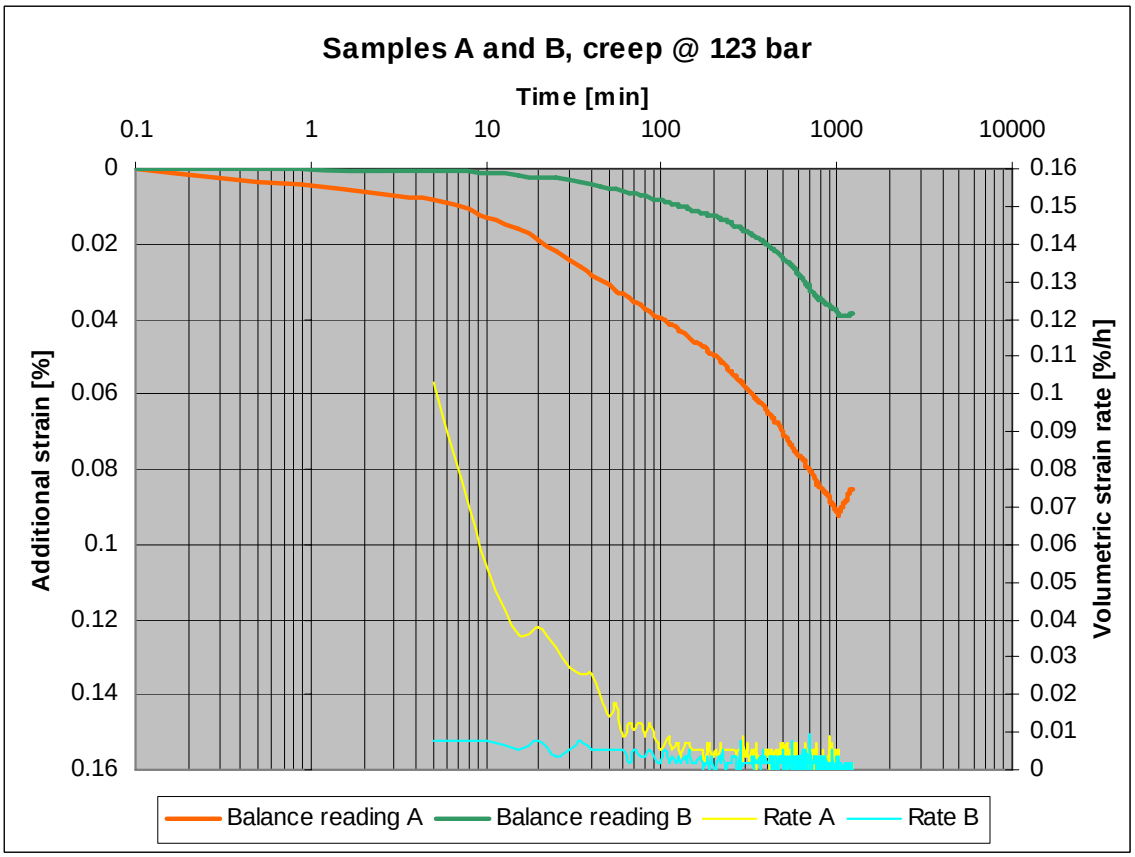
Samples 14P1 and 14P2 cont.



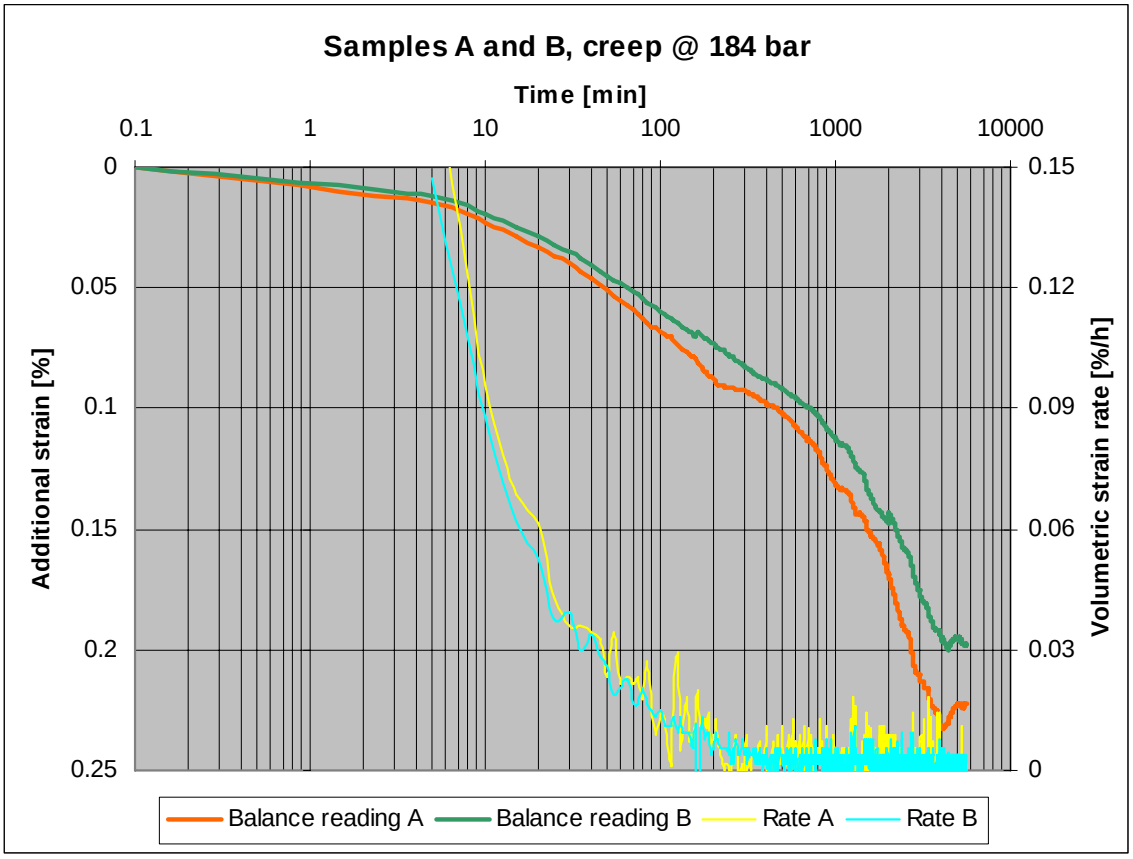


Samples A and B:

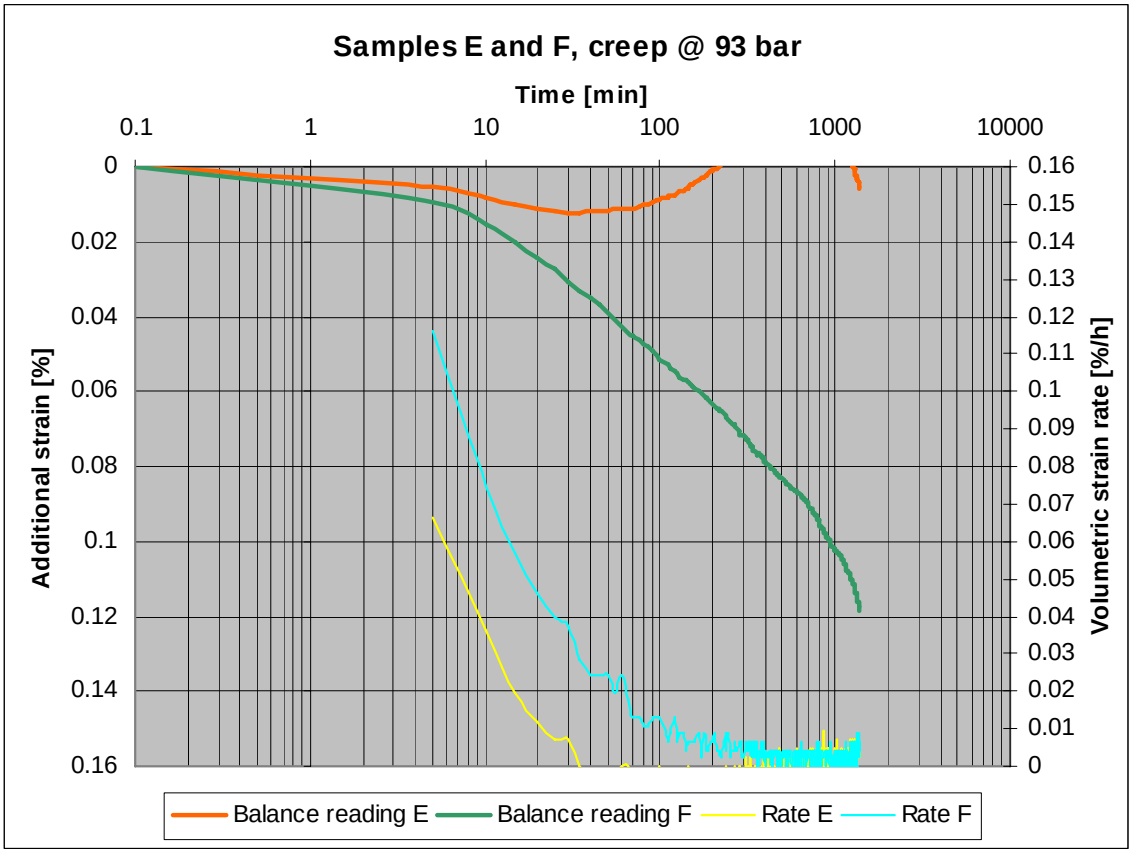


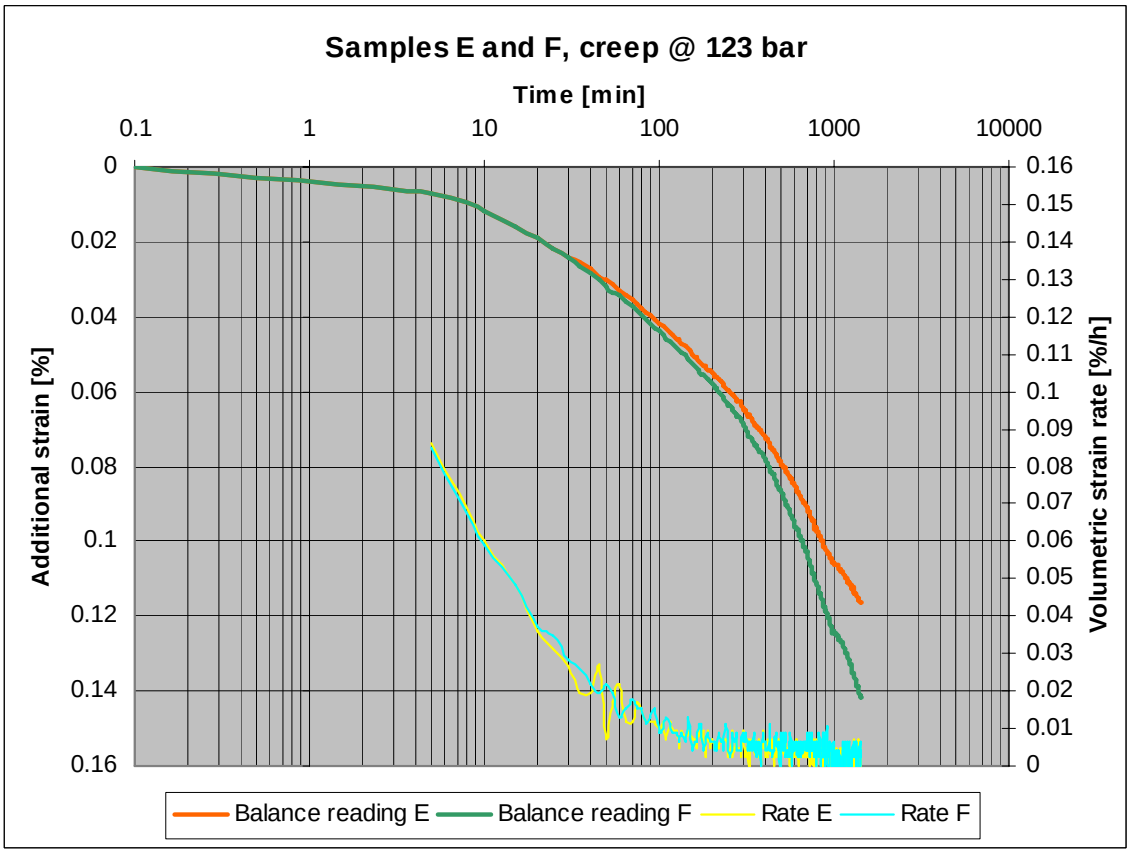


Samples A and B cont.:

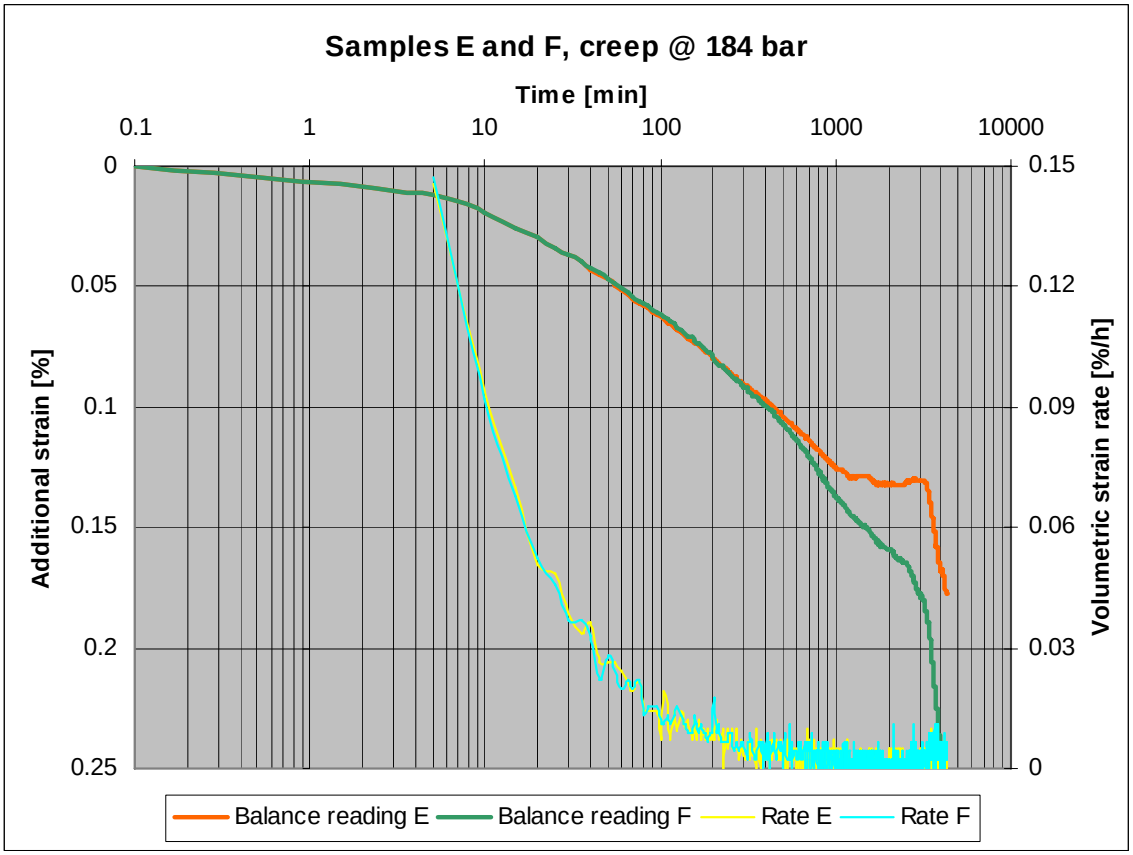


Samples E and F:





Samples E and F cont.:



5.4 Raw data

The tables below records the conventional core analysis data and the liquid baseline data @ 10 bar confining stress that is the initial condition for the compressibility experiment. The liquid squeeze-out / take-up curves during uploading / downloading steps are included as well.

Subject: Pore volume compressibility measurements — **Company: DONG E&P A/S**
C_p properties — **Well: NA-7P**
GEUS Core Lab, 05.01.2006

Room condition data: **@ 25 °C**

Plug no.	Depth	Selected for	Plug	CCAL data @ room cond.						
	m	(state)	orient.	$L_{caliper}$ [cm]	A_{calc} [cm^2]	$BV_{i(Hg)}$ [cc]	PV_i [cc]	**$Ø_i$ [%]**	**GD [g/cc]**	**K_g [mD]** @ 400 psi
6P1	2008.18	fresh	H	4.605	10.46	48.18	17.49	36.30	2.761	445
6P2	2008.28	cleaned	H	5.119	10.43	53.39	19.70	36.90	2.759	546
14P1	2016.21	fresh	H	4.684	10.54	49.39	18.18	36.80	2.728	578
14P2	2016.17	cleaned	H	5.004	10.57	52.90	19.68	37.20	2.733	554
A	2020.28	fresh	H	5.860	10.71	62.74	23.55	37.54	2.746	496
B	2020.35	fresh	V	5.625	10.74	60.42	22.62	37.43	2.738	448
E	2022.50	fresh	H	4.396	10.66	46.85	17.58	37.53	2.753	558
F	2022.60	fresh	V	4.958	10.42	51.66	19.60	37.94	2.745	nd

10 bar hydrostatic confining pressure :

Plug no.	State	Plug permeability data @ 10 bar conf. P					Balance	Unloading
		Flow rate [ml/h]	Δ P [bar]	**K_w [mD]**	**@ Sor [%]**		[g]	[g]
6P1	fresh	900	0.67	185	12		77.299	78.381
6P2	cleaned	900	0.21	659	0		27.150	29.347
14P1	fresh	900	0.46	275	9		79.514	79.726
14P2	cleaned	900	0.30	448	0		35.538	36.238
A	fresh	900	2.00	77	12		60.152	60.857
B	fresh	900	1.80	82	11		29.407	30.040
E	fresh	900	0.43	270	~16	@ Sor may be affected by grain loss	68.373	68.896
F	fresh	900	0.66	203	~15	@ Sor may be affected by grain loss	33.673	34.438

Net overburden data: **@ 25 °C**

93 bar hydrostatic confining pressure :

Plug no.	Depth	Plug porosity data @ 93 bar			Compressibility data @ 93 bar			Balance	Unloading
	m	Δ PV [cc]	PV [cc]	**Ø [%]**	BV [cc]	PV_x [cc]	C_p [bar^{-1}]	[g]	[g]
6P1	2008.18	1.15	16.34	34.74	47.03	16.34	5.48E-04	78.372	78.965
6P2	2008.28	1.18	18.52	35.47	52.21	18.55	5.60E-04	28.377	29.987
14P1	2016.21	0.85	17.33	35.70	48.54	17.36	3.40E-04	80.297	80.363
14P2	2016.17	0.91	18.77	36.10	51.99	18.79	3.82E-04	36.384	36.870
A	2020.28	1.25	22.30	36.27	61.49	22.33	4.15E-04	61.312	61.643
B	2020.35	1.20	21.41	36.16	59.22	21.44	4.05E-04	30.517	30.825
E	2022.50	0.99	16.60	36.19	45.86	16.61	4.42E-04	69.284	69.524
F	2022.60	1.27	18.33	36.38	50.39	18.36	4.96E-04	34.838	35.203

123 bar hydrostatic confining pressure :

Plug no.	Depth	Plug porosity data @ 123 bar			Compressibility data @ 123 bar			Balance	Unloading
	m	Δ PV [cc]	PV [cc]	**Ø [%]**	BV [cc]	PV_x [cc]	C_p [bar^{-1}]	[g]	[g]
6P1	2008.18	1.34	16.15	34.47	46.84	16.09	4.34E-04	78.575	78.988
6P2	2008.28	1.42	18.28	35.17	51.97	18.26	5.00E-04	28.697	29.919
14P1	2016.21	0.94	17.23	35.57	48.45	17.21	2.35E-04	80.402	80.453
14P2	2016.17	1.07	18.61	35.91	51.83	18.59	3.02E-04	36.550	36.915
A	2020.28	1.43	22.13	36.09	61.31	22.09	3.06E-04	61.493	61.726
B	2020.35	1.36	21.26	35.99	59.06	21.22	2.90E-04	30.680	30.892
E	2022.50	1.13	16.45	35.98	45.72	16.42	3.26E-04	69.440	69.606
F	2022.60	1.44	18.16	36.16	50.22	18.13	3.54E-04	35.025	35.275

153 bar hydrostatic confining pressure :

Plug no.	Depth	Plug porosity data @ 153 bar			Compressibility data @ 153 bar			Balance	Unloading
	m	Δ PV [cc]	PV [cc]	Ø [%]	BV [cc]	PV_x [cc]	C_p [bar $^{-1}$]	[g]	[g]
6P1	2008.18	1.52	15.97	34.23	46.66	15.88	3.15E-04	78.758	79.016
6P2	2008.28	1.65	18.05	34.89	51.74	18.01	4.37E-04	28.995	29.821
14P1	2016.21	1.03	17.15	35.46	48.36	17.12	1.28E-04	80.491	80.515
14P2	2016.17	1.21	18.47	35.73	51.69	18.45	2.20E-04	36.702	36.926
A	2020.28	#I/T	#I/T	#I/T	#I/T	#I/T	#I/T	nd	nd
B	2020.35	#I/T	#I/T	#I/T	#I/T	#I/T	#I/T	nd	nd
E	2022.50	#I/T	#I/T	#I/T	#I/T	#I/T	#I/T	nd	nd
F	2022.60	#I/T	#I/T	#I/T	#I/T	#I/T	#I/T	nd	nd

184 bar hydrostatic confining pressure :

Plug no.	Depth	Plug porosity data @ 184 bar			Compressibility data @ 184 bar			Balance	Unloading
	m	Δ PV [cc]	PV [cc]	Ø [%]	BV [cc]	PV_x [cc]	C_p [bar $^{-1}$]	[g]	[g]
6P1	2008.18	1.69	15.80	33.99	46.49	15.73	1.88E-04	78.938	79.020
6P2	2008.28	1.93	17.77	34.53	51.46	17.78	3.69E-04	29.357	29.724
14P1	2016.21	1.11	17.07	35.35	48.28	17.08	1.53E-05	80.573	80.567
14P2	2016.17	1.33	18.35	35.58	51.57	18.35	1.34E-04	36.832	36.932
A	2020.28	1.72	21.83	35.78	61.02	21.83	7.44E-05	61.804	61.856
B	2020.35	1.62	21.00	35.71	58.80	21.00	4.92E-05	30.957	31.004
E	2022.50	1.36	16.22	35.66	45.49	16.22	8.24E-05	69.683	69.708
F	2022.60	1.70	17.90	35.82	49.96	17.91	5.14E-05	35.303	35.364

184 bar hydrostatic confining pressure extended creep:

Plug no.	Depth	Plug porosity data @ 184 bar			Compressibility data @ 184 bar			Balance
	m	Δ PV [cc]	PV [cc]	Ø [%]	BV [cc]	PV_x [cc]	C_p [bar $^{-1}$]	[g]
6P1	2008.18	1.76	15.73	33.88	46.42			79.020
6P2	2008.28	2.09	17.61	34.32	51.30			29.724
14P1	2016.21	1.10	17.08	35.36	48.29			80.567
14P2	2016.17	1.43	18.25	35.46	51.47			36.931
A	2020.28	1.77	21.78	35.72	60.97			61.862
B	2020.35	1.66	20.95	35.66	58.76			31.004
E	2022.50	1.39	16.20	35.63	45.46			69.707
F	2022.60	1.76	17.84	35.75	49.90			35.364

Subject: Pore volume compressibility measurements — **Company: DONG E&P A/S**
Compressibility data — **Well: NA-7P**
GEUS Core Lab, 05.01.2006

Initial confining pressure: 10 bar hydrostatic
Final confining pressure: 184 bar hydrostatic

Brine d_w: 1.061 g/cc @ 25 °C
Brine μ: 1.113 cP @ 25 °C

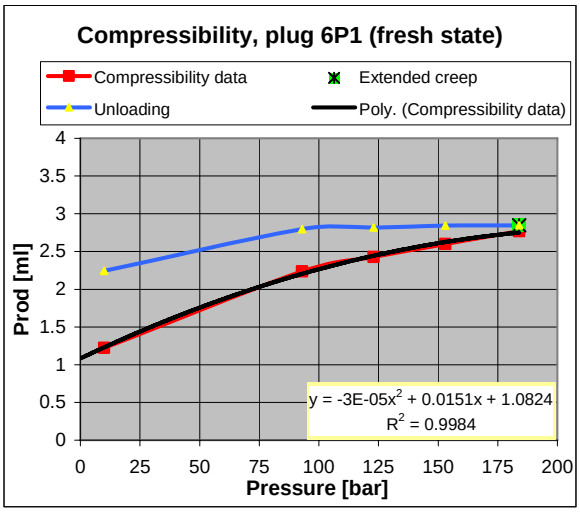
Uploading data:

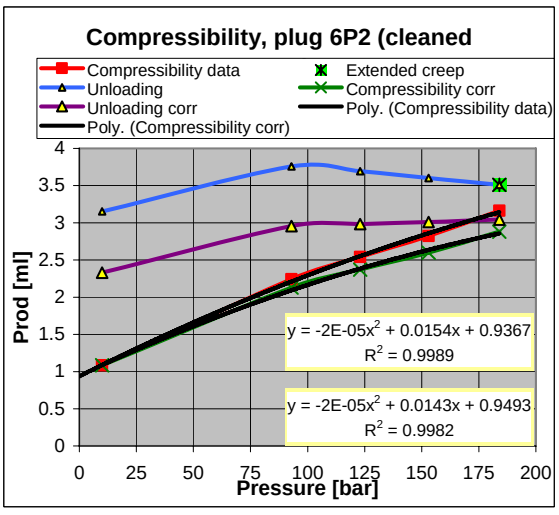
Plug no.	Depth	CCAL data @ room cond.			Readings from electronic balance [ml] @ given pressure [bar]						PV_0 from plot	ΔPV_{184bar}
	m	BV, cc	PV1, cc	Ø, %	10	93	123	153	184	184	[ml]	[ml]
6P1	2008.18	48.18	17.49	36.30	1.225	2.236	2.427	2.600	2.769	2.846	1.082	1.687
6P2	2008.28	53.39	19.70	36.90	1.083	2.241	2.542	2.823	3.164	3.509	0.937	2.227
6P2, corr	2008.28	53.39	19.70	36.90	1.083	2.129	2.370	2.598	2.880	3.043	0.949	1.931
14P1	2016.21	49.39	18.18	36.80	1.427	2.164	2.264	2.347	2.425	2.419	1.319	1.106
14P2	2016.17	52.90	19.68	37.20	1.450	2.247	2.403	2.546	2.669	2.762	1.336	1.333
A	2020.28	62.74	23.55	37.54	1.086	2.179	2.350	#I/T	2.643	2.697	0.924	1.719
B	2020.35	60.42	22.62	37.43	1.326	2.372	2.526	#I/T	2.787	2.831	1.170	1.617
E	2022.50	46.85	17.58	37.53	1.294	2.153	2.300	#I/T	2.529	2.552	1.166	1.363
F	2022.60	51.66	19.60	37.94	1.577	2.675	2.851	#I/T	3.113	3.171	1.410	1.703

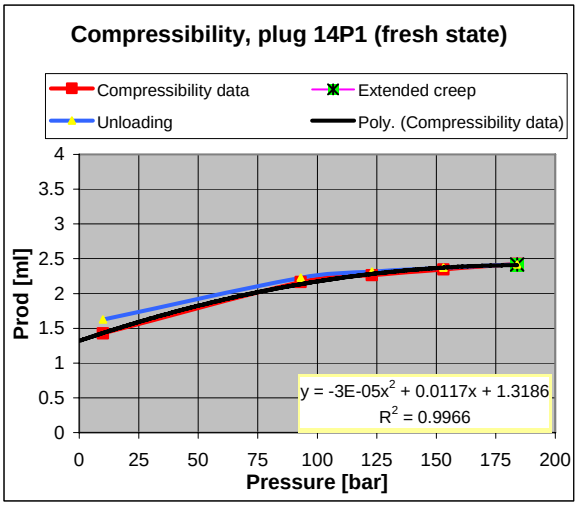
Unloading data:

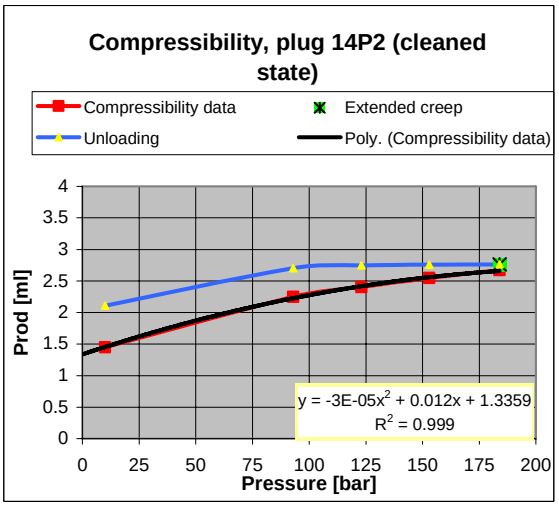
Plug no.	Depth	CCAL data @ room cond.	Readings from electronic balance [ml] @ given pressure [bar]						PV_0 from plot	ΔPV_{184bar}
	m		184	153	123	93	10		[ml]	[ml]
6P1	2008.18		2.846	2.816	2.795	2.244				
6P2	2008.28		3.510	3.601	3.694	3.758	3.154			
6P2, corr	2008.28		3.043	3.012	2.982	2.955	2.330			
14P1	2016.21		2.420	2.371	2.311	2.227	1.626			
14P2	2016.17		2.763	2.758	2.748	2.705	2.109			
A	2020.28		2.692	#I/T	2.570	2.491	1.750			
B	2020.35		2.831	#I/T	2.725	2.663	1.923			
E	2022.50		2.552	#I/T	2.456	2.379	1.787			
F	2022.60		3.171	#I/T	3.087	3.019	2.298			

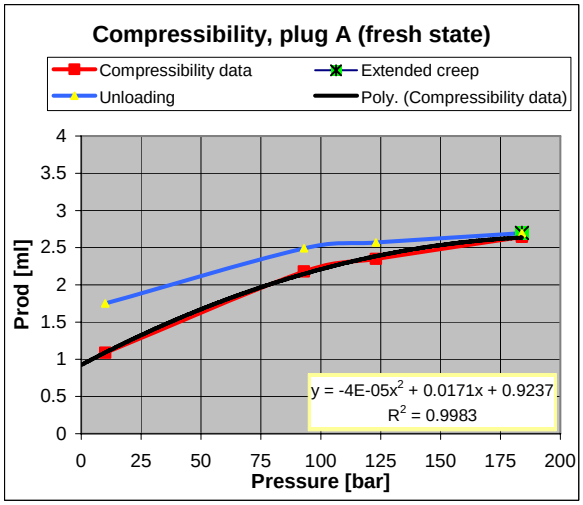
Observe that weight data from the balance have been adjusted to allow data being presented in diagrams with the same axial scaling !

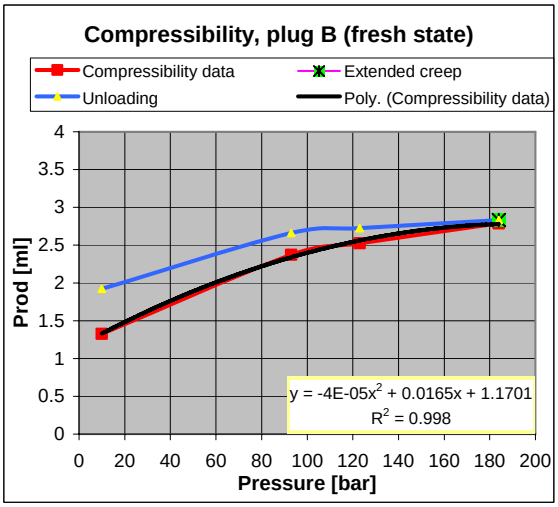


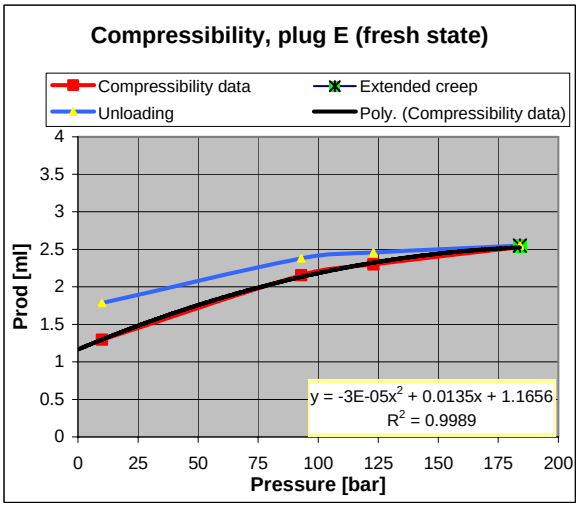


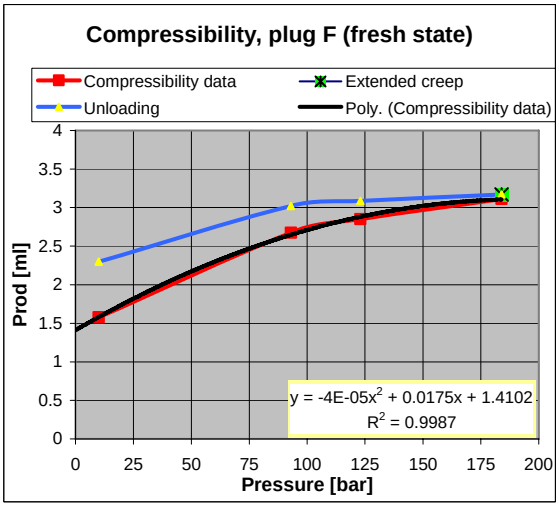

Compressibility, plug 14P1 (fresh state)
Compressibility data
Extended creep
Unloading
Poly. (Compressibility data)
Prod [ml]
Pressure [bar]
y = -3E-05x2 + 0.0117x + 1.3186
R2 = 0.9966


Compressibility, plug 14P2 (cleaned state)
Compressibility data
Extended creep
Unloading
Poly. (Compressibility data)
Prod [ml]
Pressure [bar]
y = -3E-05x2 + 0.012x + 1.3359
R2 = 0.999


Compressibility, plug A (fresh state)
Compressibility data
Extended creep
Unloading
Poly. (Compressibility data)
Prod [ml]
Pressure [bar]
y = -4E-05x2 + 0.0171x + 0.9237
R2 = 0.9983


Compressibility, plug B (fresh state)
Compressibility data
Extended creep
Unloading
Poly. (Compressibility data)
Prod [ml]
Pressure [bar]
y = -4E-05x2 + 0.0165x + 1.1701
R2 = 0.998


Compressibility, plug E (fresh state)
Compressibility data
Extended creep
Unloading
Poly. (Compressibility data)
Prod [ml]
Pressure [bar]
y = -3E-05x2 + 0.0135x + 1.1656
R2 = 0.9989


Compressibility, plug F (fresh state)
Compressibility data
Extended creep
Unloading
Poly. (Compressibility data)
Prod [ml]
Pressure [bar]
y = -4E-05x2 + 0.0175x + 1.4102
R2 = 0.9987