DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2010/125

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Mercury injection on chalk cuttings from the Halfdan Field

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Req. no.: 09201-604
Files: Mærsk-Cuttings_Phase2.doc
Hg-injection data in Excel-files

1. Introduction

By request of Mærsk Olie og Gas AS, GEUS Core Laboratory has performed special core analysis on cleaned and dried cuttings samples from the Halfdan Field, Danish North Sea.

The experimental programme was discussed with Mr. Jakob Noe-Nygaard, and confirmed in a Service Order from Mærsk Olie og Gas AS dated May 06, 2010. The following analytical programme has been carried out:

1. Additional washing, sieving and hand-picking of cuttings
2. Mercury injection capillary pressure and pore size distribution on cuttings

This study is carried out under Service Order S368039. Preliminary mercury injection data were reported to Mærsk on September 14 and October 7, 2010.

2. Analytical procedures

Mærsk Olie og Gas AS supplied 8 samples of chalk cuttings that had previously been washed and cleaned in toluene and methanol at Mærsk Laboratory. The cuttings were from the Danian (Ekofisk Fm) as well as the Maastrichtian (Tor Fm) and sampled from a number of wells in the Halfdan Field, table 2.1.

2.1 **Sample preparation**

At inspection under microscope it was obvious that the fractions needed additional cleaning for mud that still covered the cuttings and seemed to glue fragments together, figure 2.1. Repeated washing with tap water and sieving left clean fractions ready for hand picking, but only 3 samples passed a 2 mm mesh sieve with sufficient material left for a mercury injection test; for the remaining samples a 1.2 mm mesh sieve was used to get > 2.5 g material after washing. One sample from the HCA-6 well had so much material that a double determination could be carried out, table 2.1.

Table 2.1. Wet samples from the Halfdan Field and the porosity measured by mercury injection on washed, cleaned and dried cuttings fractions. Amount of cuttings remaining after hand-picking (the size fraction obtained for mercury injection test) are given in the table.

Well	Depth [feet]	Unit	Hg-porosity [%]	Cuttings fraction [g]	Fraction size [mm]
Nana-1XA	7540'	?	25.9	5.4	> 2
HBB-1	11400' – 11460'	M1A	23.1	4.0	> 1.2
HBB-1	18480' – 18570'	M1A	22.2	2.7	> 1.2
HBB-7	15340' – 15400'	M1B	30.2	6.6	> 1.2
HBB-7	19820'	M1B	28.4	2.5	> 1.2
HCA-6	11810' – 11840'	D1a	26.1	5.7	> 2
HCA-6	11870' – 11900'	D1a	30.4	8.5	> 1.2
HCA-6	12740' – 12770'	D2a	32.9	17.3	> 2
HCA-6	12740' – 12770'	D2a	29.0	17.3	> 2

Figure 2.1. Photos of washed and cleaned cuttings fractions. Some samples had problems with mud sticking to the surface of cuttings (left), even after the initial washing and cleaning; an additional sieving and washing under tap water cleaned up the cuttings. Non-chalk constituents, mis-coloured or iron-coated cuttings were removed by hand picking or a magnet (right). Credit: Mærsk Laboratory.

3. Analytical Methods

3.1 Mercury injection

SKM Services utilises a Micromeritics Autopore-IV porosimeter. Hg capillary pressure is measured in an injection sweep from vacuum to 60.000 psia [400 MPa]. Pore throat sizes can be measured from 200 µm down to ~ 3 nm, covering pore size distributions in the micro-, meso- and macropore range.

Mercury injection pore volume is reported by the Autopore IV as a cumulative volume of mercury injected into the sample void space, at the maximum injection pressure of 60,000 psi. The injection is reported in cc. per gram and thus must be multiplied by the total sample weight to obtain the total volume of mercury injected – the mercury pore volume:

$$Hg\ Pore\ Volume\ [cc] = Cumulative\ Hg\ Injection\ [g/cc] * Sample\ Weight\ [g].$$

At any injection pressure the minimum pore throat radius 'r' that can be penetrated by mercury is obtained from Purcell's eq.:

$$P_c = \frac{2\gamma \times \cos\theta}{r} * C \quad , \quad \text{where}$$

P_c – capillary pressure [Psia]
r – capillary radius [µm]
γ – interfacial tension, air-mercury system 480 [dyn/cm]
θ – contact angle, air-mercury system 140 [degrees]
C – conversion constant, 0.145

The mean hydraulic radius given in the diagrams is the average pore throat size of the sample [µm].

The first derivative of the fractional saturation vs. pore throat size function is the pore throat size distribution function PSD:

PSD = dv /dlog (r)

PSD is normalized to 1 and shown in a distribution function diagram along with the permeability distribution function against pore throat radius.

The Leverett J-function (dimensionless) correlates P_c with pore structure and is plotted against the wetting phase saturation:

$$J = \frac{P_c \sqrt{\frac{k}{\emptyset}}}{\gamma \times \cos\theta} * C \quad , \text{where}$$

k – permeability [mD]
Ø – porosity [fraction]
C – conversion constant, 0.2166

4. Results

4.1 Single sample diagrams

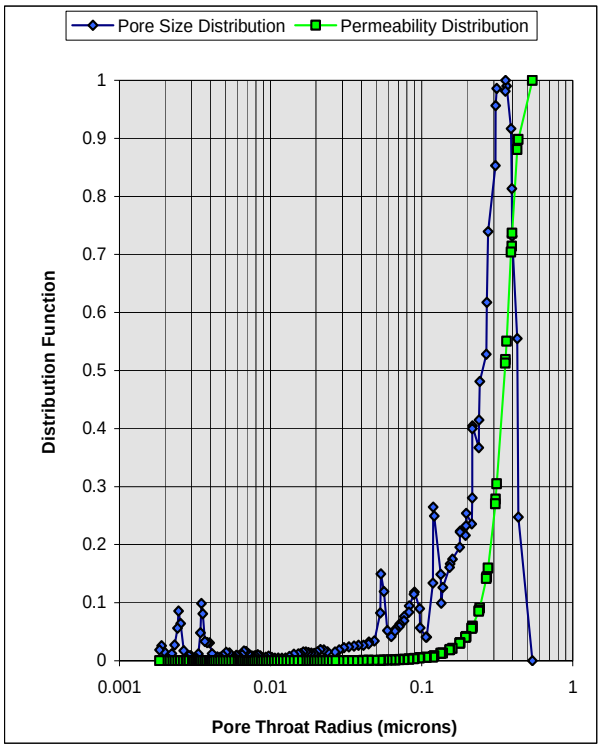
Results for the single samples are given in the diagrams below. Additional diagrams and raw data can be found from the attached CD-ROM. A copy of the report in pdf-file format is included with the CD-ROM as well.

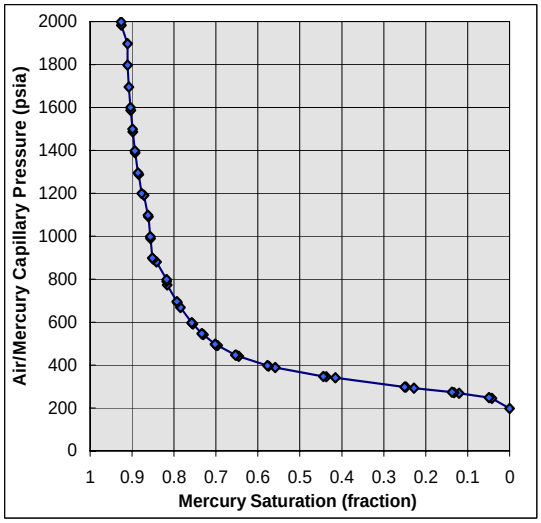
Subject: Mercury injection data **Well : Nana-1XA**
Project : Hg-injection on chalk cuttings
Drainage data to 60.000 psia (4kbar) **GEUS Core Lab and SKM Services, 14.09.2010**

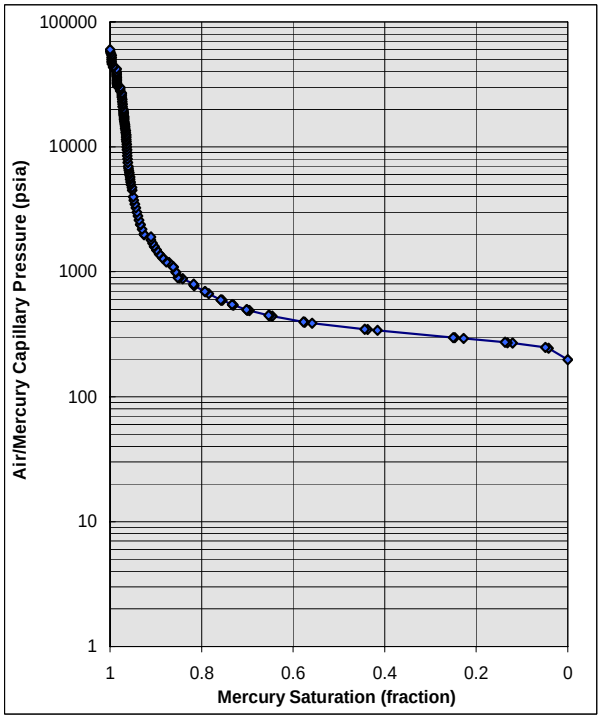
Plug ID	1XA	>2 mm
Plug Depth	7540.00	ft
Plug Permeability (Air)	n/a	[mD]
Plug Porosity (He)	n/a	fraction

Injection Sample Porosity	0.259	fraction
Injection Sample Pore Vol	0.450	[cc]
Injection Sample Bulk Vol	1.738	[cc]
Injection Sample Weight	3.510	g

Mean Hydraulic Radius	0.154	[µm]
Swanson's Parameter	0.038	
FZI		





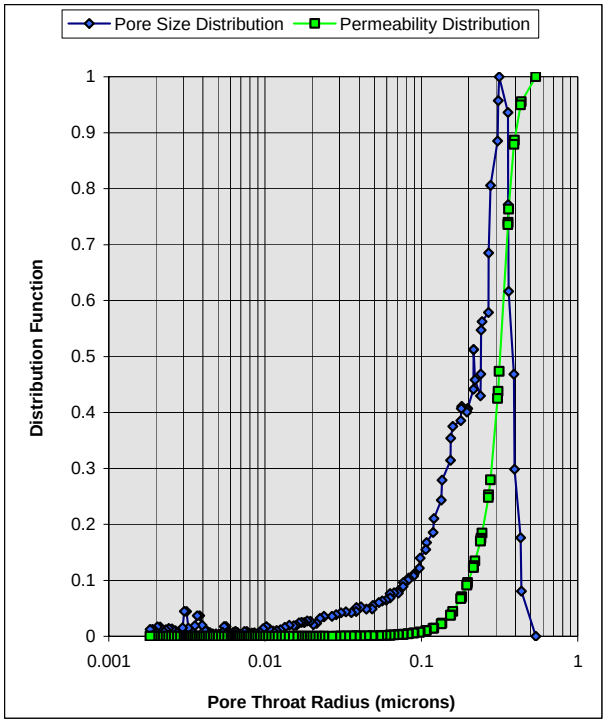


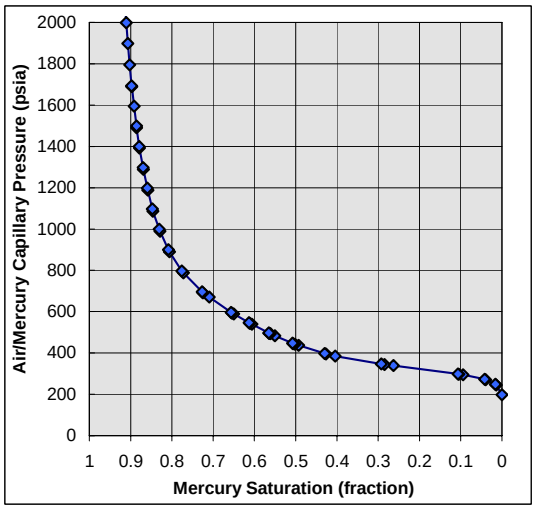
Subject: Mercury injection data **Well : HBB-1**
Project : Hg-injection on chalk cuttings
Drainage data to 60.000 psia (4kbar) **GEUS Core Lab and SKM Services, 14.09.2010**

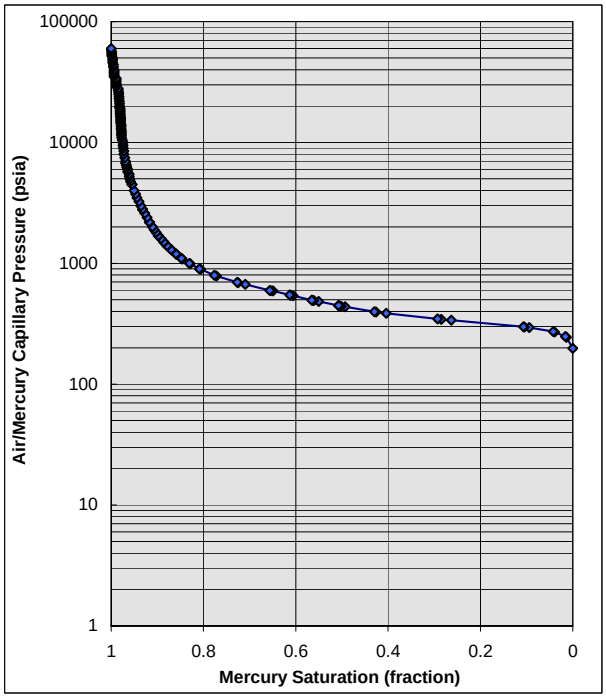
Plug ID	1 (M1A)	>1.2 mm
Plug Depth	11400 - 11460	ft
Plug Permeability (Air)	n/a	[mD]
Plug Porosity (He)	n/a	fraction

Injection Sample Porosity	0.231	fraction
Injection Sample Pore Vol	0.445	[cc]
Injection Sample Bulk Vol	1.925	[cc]
Injection Sample Weight	3.970	g

Mean Hydraulic Radius	0.135	[µm]
Swanson's Parameter	0.026	
FZI		





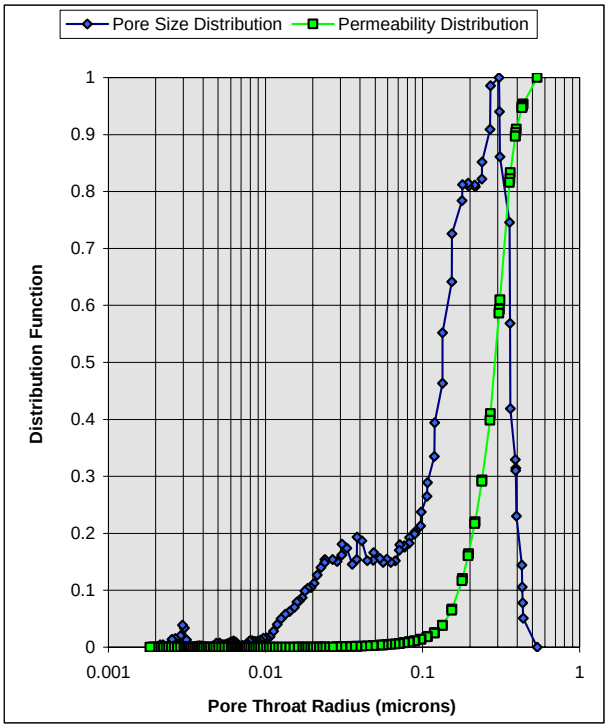


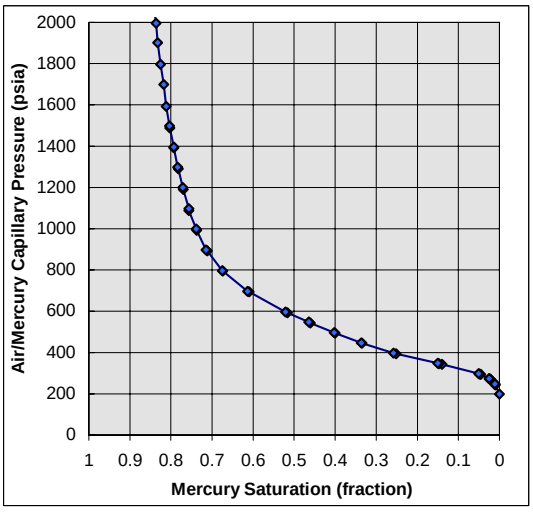
Subject: Mercury injection data **Well : HBB-1**
Project : Hg-injection on chalk cuttings
Drainage data to 60.000 psia (4kbar) **GEUS Core Lab and SKM Services, 14.09.2010**

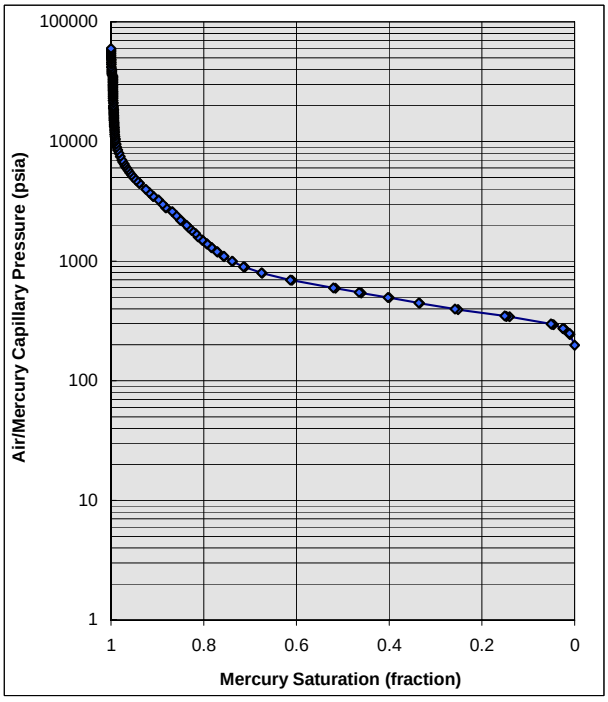
Plug ID	2 (M1A)	>1.2 mm
Plug Depth	18480 18570	ft
Plug Permeability (Air)	n/a	[mD]
Plug Porosity (He)	n/a	fraction

Injection Sample Porosity	0.222	fraction
Injection Sample Pore Vol	0.280	[cc]
Injection Sample Bulk Vol	1.261	[cc]
Injection Sample Weight	2.630	g

Mean Hydraulic Radius	0.118	[µm]
Swanson's Parameter	0.020	
FZI		





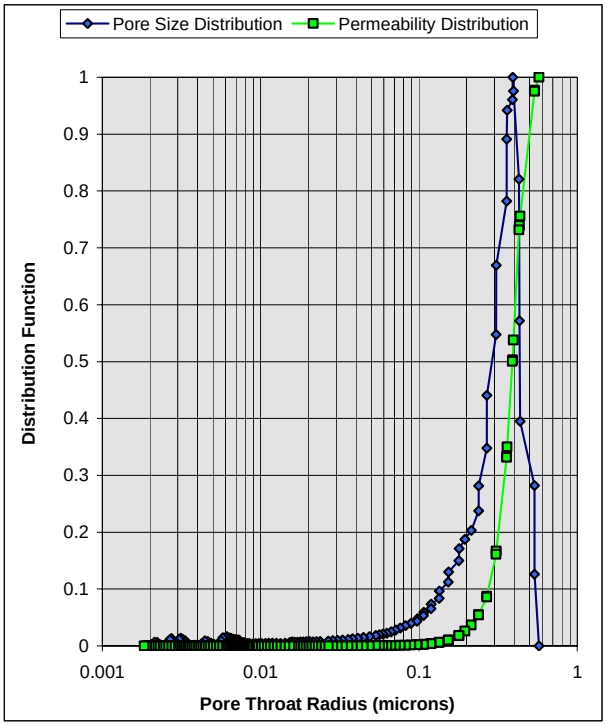


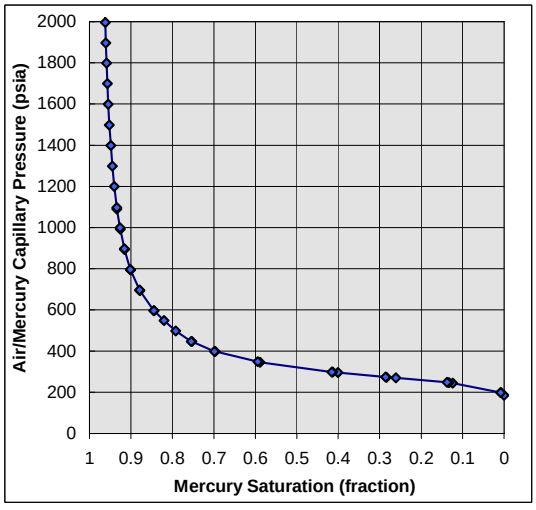
Subject: Mercury injection data **Well : HBB-7**
Project : Hg-injection on chalk cuttings
Drainage data to 60.000 psia (4kbar) **GEUS Core Lab and SKM Services, 14.09.2010**

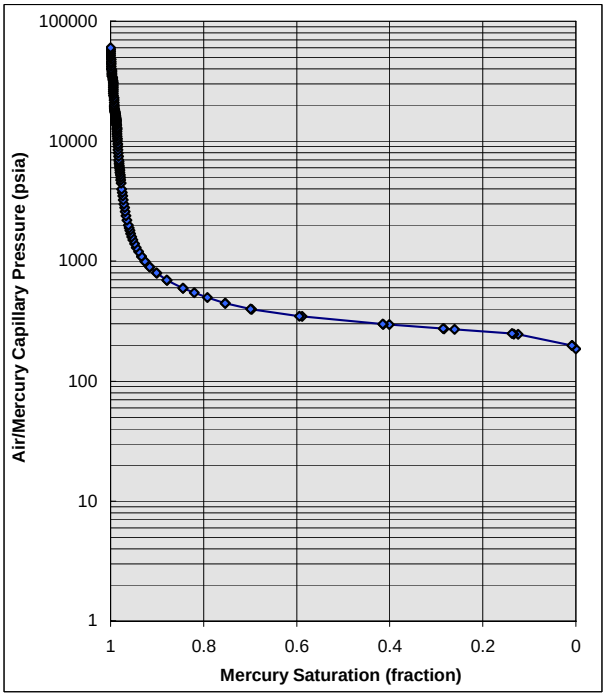
Plug ID	1 (M1B)	>1.2 mm
Plug Depth	15340 -15400	ft
Plug Permeability (Air)	n/a	[mD]
Plug Porosity (He)	n/a	fraction

Injection Sample Porosity	0.302	fraction
Injection Sample Pore Vol	0.285	[cc]
Injection Sample Bulk Vol	0.946	[cc]
Injection Sample Weight	1.750	g

Mean Hydraulic Radius	0.169	[µm]
Swanson's Parameter	0.053	
FZI		





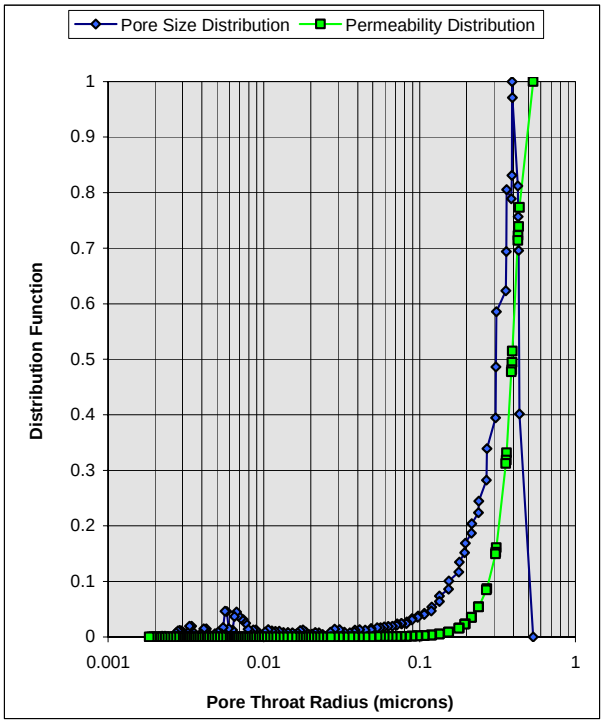


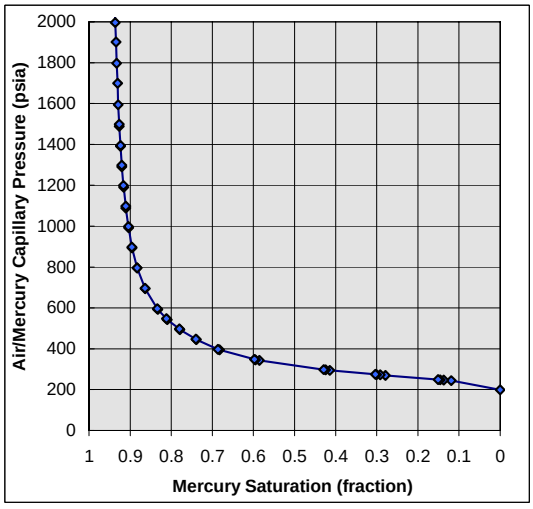
Subject: Mercury injection data **Well : HBB-7**
Project : Hg-injection on chalk cuttings
Drainage data to 60.000 psia (4kbar) **GEUS Core Lab and SKM Services, 14.09.2010**

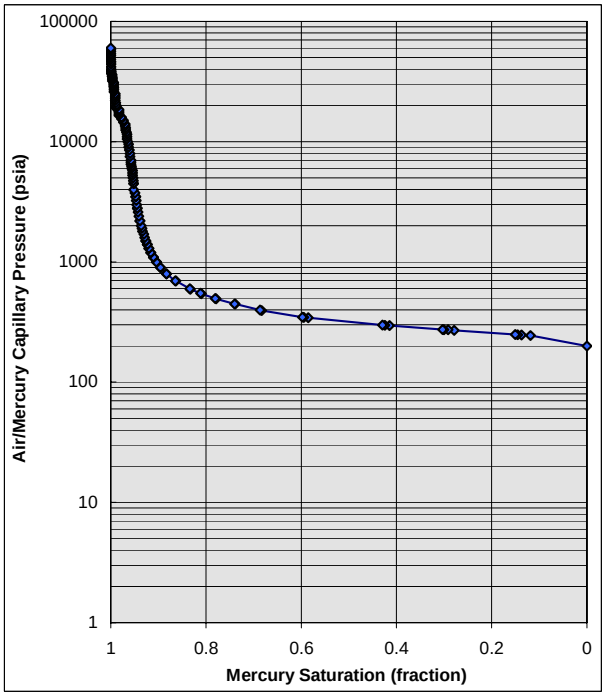
Plug ID	2 (M1B)	>1.2 mm
Plug Depth	19790 - 19850	ft
Plug Permeability (Air)	n/a	[mD]
Plug Porosity (He)	n/a	fraction

Injection Sample Porosity	0.284	fraction
Injection Sample Pore Vol	0.397	[cc]
Injection Sample Bulk Vol	1.397	[cc]
Injection Sample Weight	2.490	g

Mean Hydraulic Radius	0.171	[µm]
Swanson's Parameter	0.049	
FZI		





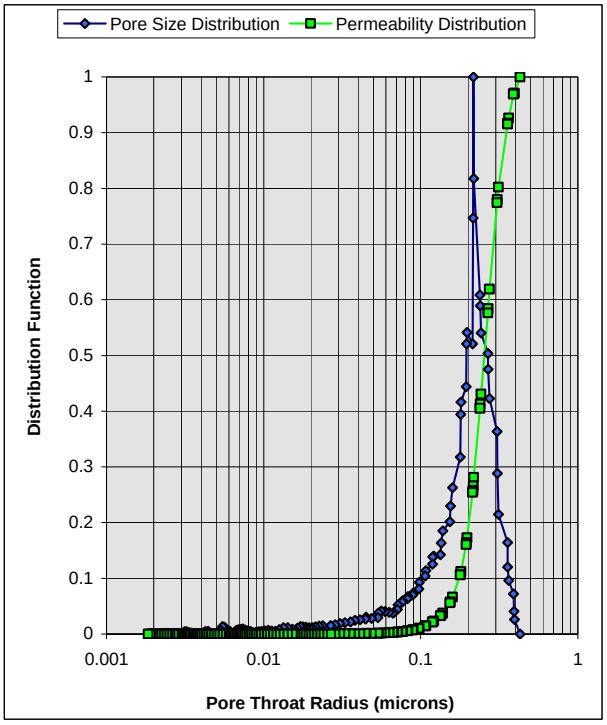


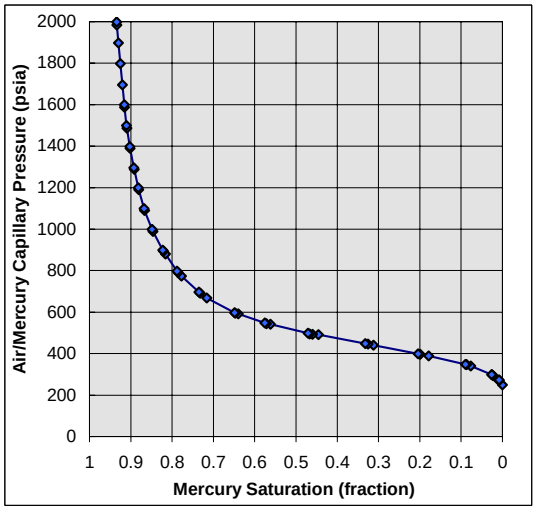
Subject: Mercury injection data **Well : HCA-6**
Project : Hg-injection on chalk cuttings
Drainage data to 60.000 psia (4kbar) **GEUS Core Lab and SKM Services, 14.09.2010**

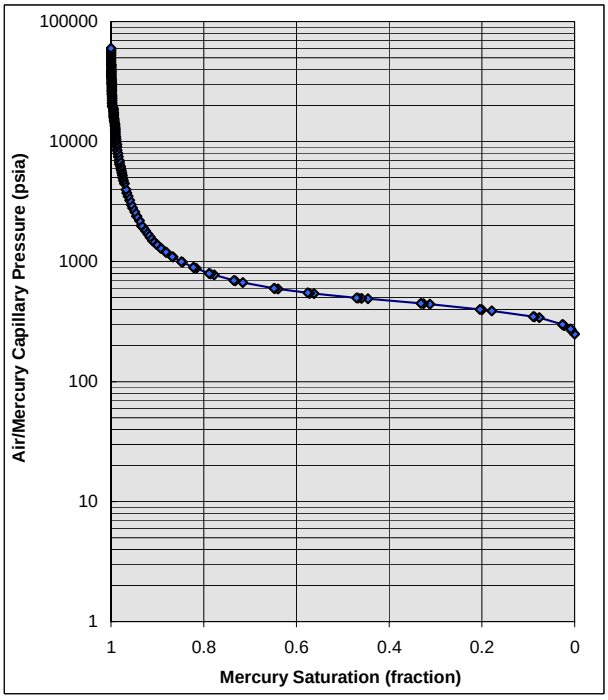
Plug ID	1 (D1a)	>2 mm
Plug Depth	11810-11840	ft
Plug Permeability (Air)	n/a	[mD]
Plug Porosity (He)	n/a	fraction

Injection Sample Porosity	0.261	fraction
Injection Sample Pore Vol	0.768	[cc]
Injection Sample Bulk Vol	2.948	[cc]
Injection Sample Weight	4.840	g

Mean Hydraulic Radius	0.113	[µm]
Swanson's Parameter	0.028	
FZI		





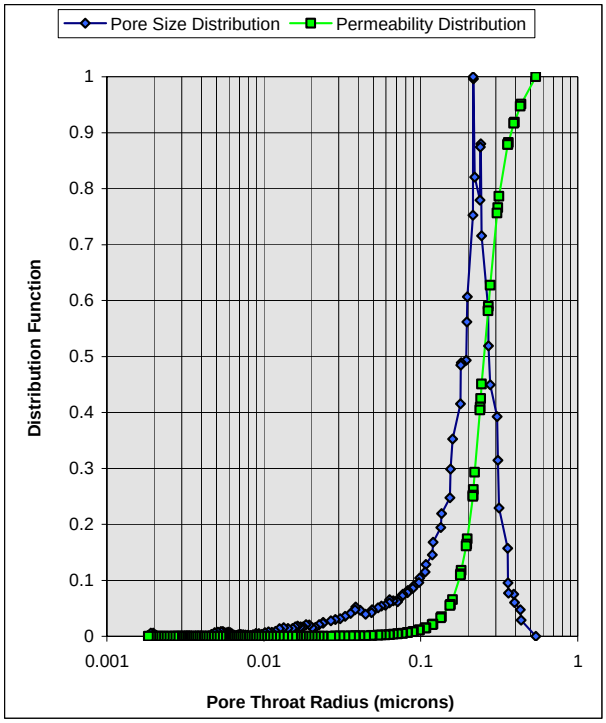


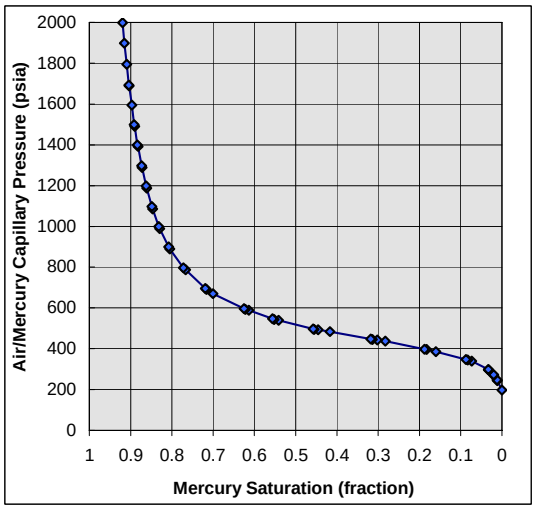
Subject: Mercury injection data **Well : HCA-6**
Project : Hg-injection on chalk cuttings
Drainage data to 60.000 psia (4kbar) **GEUS Core Lab and SKM Services, 14.09.2010**

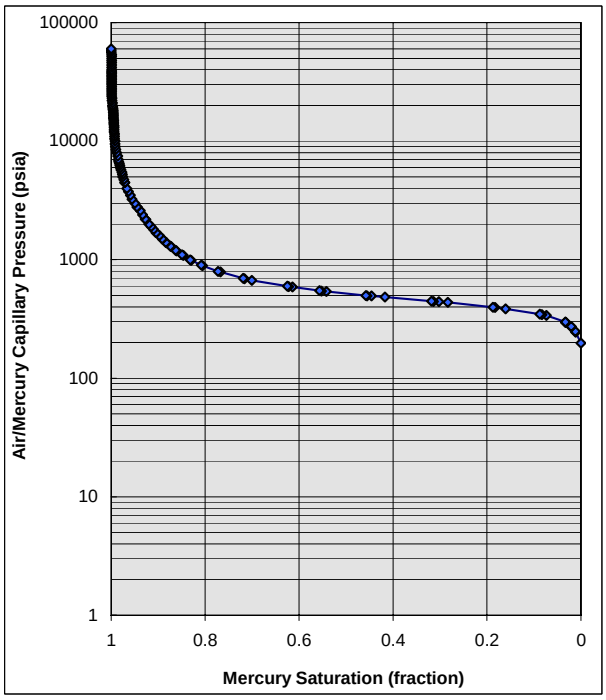
Plug ID	2 (D1a)	>1.2 mm
Plug Depth	11870 - 11900	ft
Plug Permeability (Air)		[mD]
Plug Porosity (He)		fraction

Injection Sample Porosity	0.304	fraction
Injection Sample Pore Vol	1.364	[cc]
Injection Sample Bulk Vol	4.485	[cc]
Injection Sample Weight	8.380	g

Mean Hydraulic Radius	0.114	[µm]
Swanson's Parameter	0.032	
FZI		







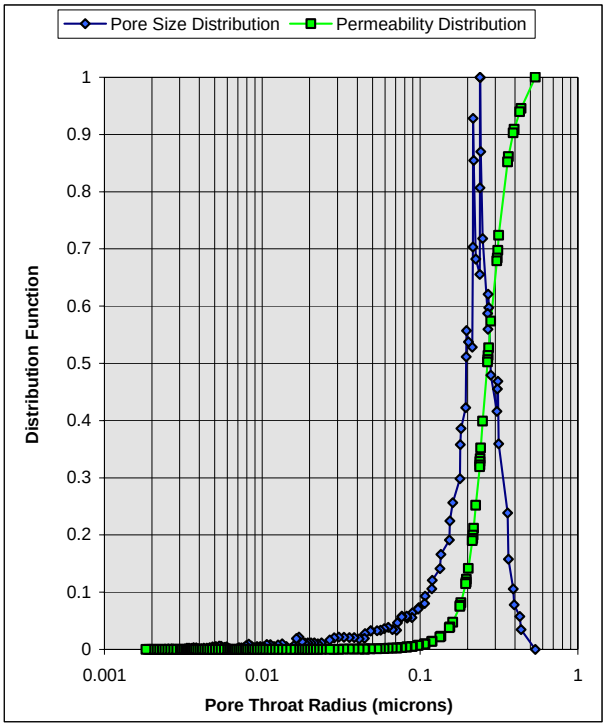
Subject: Mercury injection data **Well : HCA-6**
Project : Hg-injection on chalk cuttings
Drainage data to 60.000 psia (4kbar) **GEUS Core Lab and SKM Services, 14.09.2010**

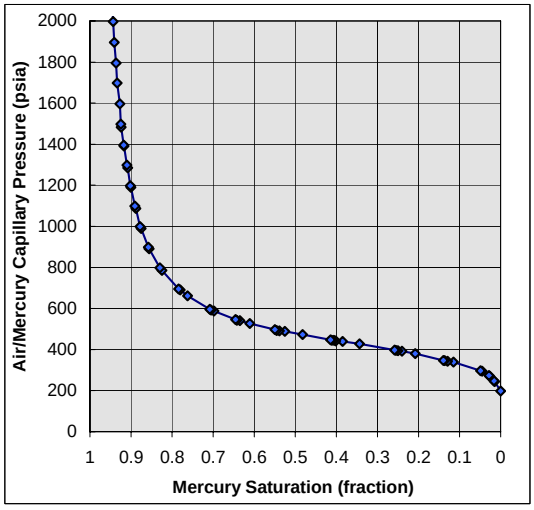
Plug ID	3a (D2a)	>2 mm
Plug Depth	12740 - 12770	ft
Plug Permeability (Air)	n/a	[mD]
Plug Porosity (He)	n/a	fraction

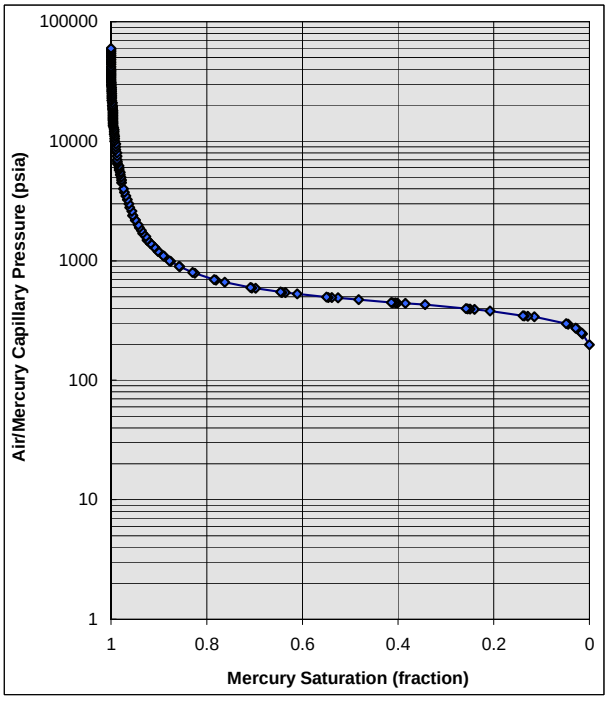
Injection Sample Porosity	0.329	fraction
Injection Sample Pore Vol	1.350	[cc]
Injection Sample Bulk Vol	4.105	[cc]
Injection Sample Weight	7.370	g

Mean Hydraulic Radius	0.123	[µm]
Swanson's Parameter	0.039	
FZI		

NB: Samples 3a and 3b are double determinations on aliquots from one cuttings sample







Subject: Mercury injection data **Well : HCA-6**
Project : Hg-injection on chalk cuttings
Drainage data to 60.000 psia (4kbar) **GEUS Core Lab and SKM Services, 14.09.2010**

Plug ID	3b (D2a)	>2 mm
Plug Depth	12740 - 12770	ft
Plug Permeability (Air)	n/a	[mD]
Plug Porosity (He)	n/a	fraction

Injection Sample Porosity	0.290	fraction
Injection Sample Pore Vol	1.211	[cc]
Injection Sample Bulk Vol	4.173	[cc]
Injection Sample Weight	6.830	g

Mean Hydraulic Radius	0.119	[µm]
Swanson's Parameter	0.035	
FZI		

NB: Samples 3a and 3b are double determinations on aliquots from one cuttings sample