DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2001/91

Conventional Core Analysis for Mærsk Olie og Gas A/S

Well: Gorm N-54

Core Laboratory
Niels Springer and Niels Stentoft

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF ENVIRONMENT AND ENERGY

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1 Introduction

By request of Mærsk Olie og Gas A/S, GEUS Core Laboratory has performed conventional core analysis on the Gorm N-54 well, Danish North Sea.

The experimental programme was specified in a facsimile message from Mr. Alexis Sørensen, dated May 23, 2001. The following analytical programme has been carried out:

- Fluid saturation determination by Dean Stark extraction
- Soxhlet cleaning and drying
- Unconfined Helium porosity and grain density
- Gas permeability and Klinkenberg corrected gas permeability @ 800 psi confining pressure
- Lithological description of plugs following guidelines given by the Joint Chalk Research Program

This study is carried out under contract GSC 1418, CWO 192. Preliminary data have been reported to Mærsk during July and early August, 2001.

2 Sampling and analytical procedures

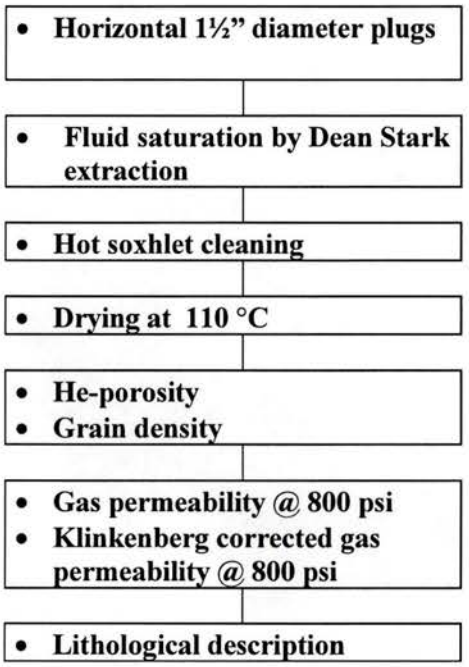
2.1 Sampling

A total of 7 plugs preserved in mud was received from Mærsk Laboratory. All plugs were horizontal 1½" diameter plugs cut from the high porosity part of the Maastrichtian chalk unit.

2.2 Analytical

The plugs were trimmed to a length of approx. 2½", Dean Starked, Soxhlet cleaned and dried at 110 °C. A fluid density of 0.85 g/cc for oil and 1.022 g/cc for water at surface conditions have been assumed in the calculation of fluid saturation. Plugs were then analyzed for porosity (un-confined) and gas permeability using a confining sleeve pressure of 800 psi. The plugs were finally lithologically described to the guidelines established by Joint Chalk Research. Results are presented in section 5.

3 Flow diagram of the analytical procedures



4 Analytical Methods

The following is a short description of the methods used by the Core Analysis Laboratory. For a more detailed description of methods, instrumentation and principles of calculation the reader is referred to API recommended practice for core-analysis procedure (API RP 40, 2nd ed. 1998).

4.1 Conventional cleaning and drying

The samples are placed in a Soxhlet extractor, which continuously soaks and washes the samples with methanol. This process removes water and dissolves salt precipitated in the pore space of the rock. Extraction is terminated when no chloride ions are present in the methanol. Samples containing hydrocarbons are then cleaned in toluene until a clear solution is obtained. Samples are vacuum dried at 90 °C or 110 °C, or they are humidity dried at 60 °C and 40% relative humidity until constant weight occurs, depending on the requirements of the client.

4.2 Gas permeability

The plug is mounted in a Hassler core holder, and a confining pressure of 800 psi applied to the sleeve. The specific permeability to gas is measured by flowing nitrogen gas through a plug of known dimensions at differential pressures between 0 and 1 bar. No back pressure is applied. The readings of the digital gas permeameter are checked regularly by measurement of permeable steel reference plugs (Core Laboratories™ gas permeability reference plug set).

4.3 Klinkenberg permeability

The Klinkenberg corrected gas permeability, sometimes termed the equivalent liquid permeability, is calculated from gas permeability measurements performed at 3 different mean pressures in the plug sample.

The plug is mounted in a Hassler core holder, and a confining pressure of 800 psi is applied to the sleeve. Nitrogen gas pressures of 3, 5 and 8 atm. (abs.) are applied at the upstream end of the plug, and the downstream pressure is regulated until a suitable flow is obtained. The differential pressure is kept approx. constant in order to maintain a similar flow regime during the 3 measurements. When a steady state is reached, the upstream pressure, the differential pressure across the plug and the flow reading is recorded. A linear regression of permeability on inverse mean pressure is performed for the 3 measurements, and the intercept on the permeability axis is the Klinkenberg corrected gas permeability. To ensure compatibility with plug data which do not include Klinkenberg corrected gas permeability, a permeability value pertaining to a mean pressure of 1.5 atm. (abs) is calculated from the Klinkenberg regression coefficients. This value is reported as "1.5 P-M permeability" in the core analysis tabulation, and should be comparable to the conventional gas permeability which is measured at the same mean pressure.

Klinkenberg corrected gas permeabilities are only reported down to approx. 0.1 mD on normal routine terms. However, on request measurements can be carried out to a lower limit of 0.01 mD. The performance of the digital gaspermeameter is checked regularly by measurements of permeable steel reference plugs (Core Laboratories™ gas permeability reference plug set).

4.4 He-porosity and grain density

The porosity is measured on cleaned and dried samples. The porosity is determined by subtraction of the measured grain volume and the measured bulk volume. The Helium technique, employing Boyle's Law, is used for grain volume determination, applying a double chambered Helium porosimeter with digital readout, whereas bulk volume is measured by submersion of the plug in a mercury bath using Archimedes principle. Grain density is calculated from the grain volume measurement and the weight of the cleaned and dried sample.

4.5 Fluid saturation

The water content of a plug is extracted by Dean Stark distillation with toluene. The water is retained by a condenser, and the amount is directly measured in a calibrated trap. The oil content of the plug is dissolved in the toluene. The quantity of oil is calculated as the difference between the original sample weight and the weight after extraction, corrected for the amount of water recovered. The plug is finally Soxhlet cleaned to remove salt precipitated in the pore space. The porosity is then measured as described above.

The calculation of fluid saturation presumes that the water and oil density is known. If it is unknown, a value is assumed in the final calculation, usually 1.0 g/ml for the brine and 0.85 g/ml for the oil. The percentage of the plug pore volume which is not occupied by either water or oil is the gas saturation.

4.7 Precision of analytical data

The table below gives the precision (= reproducibility) at the 68% level of confidence (+/- 1 standard deviation) for routine core analysis measurements performed at GEUS Core Laboratory:

Measurement	Range, mD	Precision
Bulk volume, Hg		0.01 cc
- " - , Archimedes		0.1 cc
Grain density		0.003 g/cc
Porosity		0.1 porosity-%
Permeability: (Klinkenberg)	0.01-0.1 0.1-1 > 1	15% 10% 4%
Permeability: (Conventional)	0.001-0.01 0.01-0.1 > 0.1	25% 15% 4→3%

The precision of the fluid saturation determination depends on the pore volume of the plug. The greater the plug and the greater the porosity of the plug, the better precision is obtained. The following table gives the precision in absolute percent-point:

Porosity	1" x 1.5" plugs	1.5" x 3" plugs
> 20%	5%	1%
10-20%	10%	2%
5-10%	20%	5%
< 5%	> 20%	> 5%

Certain factors might alter the stated precision of the fluid saturation determination. Loss of material during handling of the plug will result in an increase in the calculated oil saturation, and a similar decrease in the calculated gas saturation. This may occur for fragile for loosely consolidated rocks or if the rock contains dissolvable matters like halite. As the lost material usually has a greater density than oil, it may happen that the estimated volume of oil and the measured volume of water all together take up more space than the actual pore volume after cleaning.

5. Results

5.1 Conventional core analysis data

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND

GEUS CORE LABORATORY

CORE ANALYSIS TABULATION

FINAL REPORT

Compiled by Niels Springer

WELL : Gorm N-54

CORE :

Printed : 10-SEP-01

GENERAL INFORMATION ON THE ANALYSIS

COMPANY : Maersk Olie & Gas	LOCATION : Danish North Sea
DEPTH INTERVAL : 8217.17 - 8240.58	CORE NO.'S :
DEPTHS ARE MEASURED FROM KB	ANALYSTS : MJ, GG
DEPTHS ARE IN FEET	DATE : 1009 1
PROGRAM POPE V.5.*	FILE : N-54

REMARKS :

Plugs have been soxhlet cleaned in methanol and toluene and dried at 110 C. Helium porosity was measured unconfined, gas permeability was measured at a confining sleeve pressure of 800 psi.

SAMPLE NO.	DEPTH FEET	PLUG TYPE	GAS PERM mD	1.5 P-M PERM mD	KLINK PERM mD	KLINK CORR. COEF.	POROSITY %	GRAIN DENS. G/CCM	WATER SATUR. %	OIL SATUR. %	GAS SATUR. %
1	8217.17	HOR	3.42	3.33	1.80	1.000	44.32	2.702	66	18	16
2	8221.50	HOR	2.53	2.43	1.30	0.995	42.61	2.698	16	59	25
3	8225.33	HOR	3.05	3.00	1.56	0.999	44.06	2.697	16	64	20
4	8229.33	HOR	3.21	3.17	1.69	0.999	43.74	2.692	12	58	30
5	8233.25	HOR	4.22	4.18	2.43	0.999	44.10	2.696	16	62	22
6	8237.17	HOR	4.44	4.28	2.50	0.999	44.99	2.700	15	68	17
7	8240.58	HOR	4.10	4.02	2.20	1.000	44.40	2.699	13	68	19

STATISTICAL INFORMATION ON THE POROSITY - GAS PERMEABILITY RELATIONSHIP
CALCULATED ONLY FROM SAMPLES WITH NON-ZERO PERMEABILITY.

NUMBER OF SAMPLES	:	7	

SINGLE-SAMPLE STATISTICS:

POROSITY:

MEAN POROSITY	:	44.03	%
VARIANCE ON POROSITY	:	0.54	%**2

PERMEABILITY:

GEOMETRIC AVERAGE	:	3.51	mD
ARITHMETRIC AVERAGE	:	3.57	mD
HARMONIC AVERAGE	:	3.44	mD

STATISTICS CALCULATED FROM LINEAR REGRESSION OF PERMEABILITY ON POROSITY:

MODEL: LOG10(PERMEABILITY) = INTERCEPT + SLOPE*POROSITY + RESIDUAL

DEGREES OF FREEDOM	:	5	
COEFFICIENT OF DETERMINATION	:	0.746	
STANDARD ERROR ON THE REGRESSION	:	0.049	log(mD)
ESTIMATED INTERCEPT	:	-4.011	log(mD)
ESTIMATED STANDARD ERROR ON INTERCEPT	:	1.190	log(mD)
ESTIMATED SLOPE	:	0.10348	log(mD)/%
ESTIMATED STANDARD ERROR ON SLOPE	:	0.02703	log(mD)/%

PLEASE REMARK THAT THE REGRESSION STATISTICS PERTAIN TO LOG PERMEABILITY VALUES.
THE COEFFICIENT OF DETERMINATION GIVES THE FRACTION AF THE TOTAL VARIATION SQUARED
WHICH IS EXPLAINED BY THE MODEL.
THE STANDARD ERROR ON THE REGRESSION GIVES THE MEAN 1 SIGMA ERROR ON THE LOG
PERMEABILITY ESTIMATES.

STATISTICAL INFORMATION ON THE POROSITY - KLINKENBERG PERM. RELATIONSHIP
CALCULATED ONLY FROM SAMPLES WITH NON-ZERO PERMEABILITY.

NUMBER OF SAMPLES	:	7	

SINGLE-SAMPLE STATISTICS:

POROSITY:

MEAN POROSITY	:	44.03	%
VARIANCE ON POROSITY	:	0.54	%**2

PERMEABILITY:

GEOMETRIC AVERAGE	:	1.88	mD
ARITHMETRIC AVERAGE	:	1.92	mD
HARMONIC AVERAGE	:	1.83	mD

STATISTICS CALCULATED FROM LINEAR REGRESSION OF PERMEABILITY ON POROSITY:

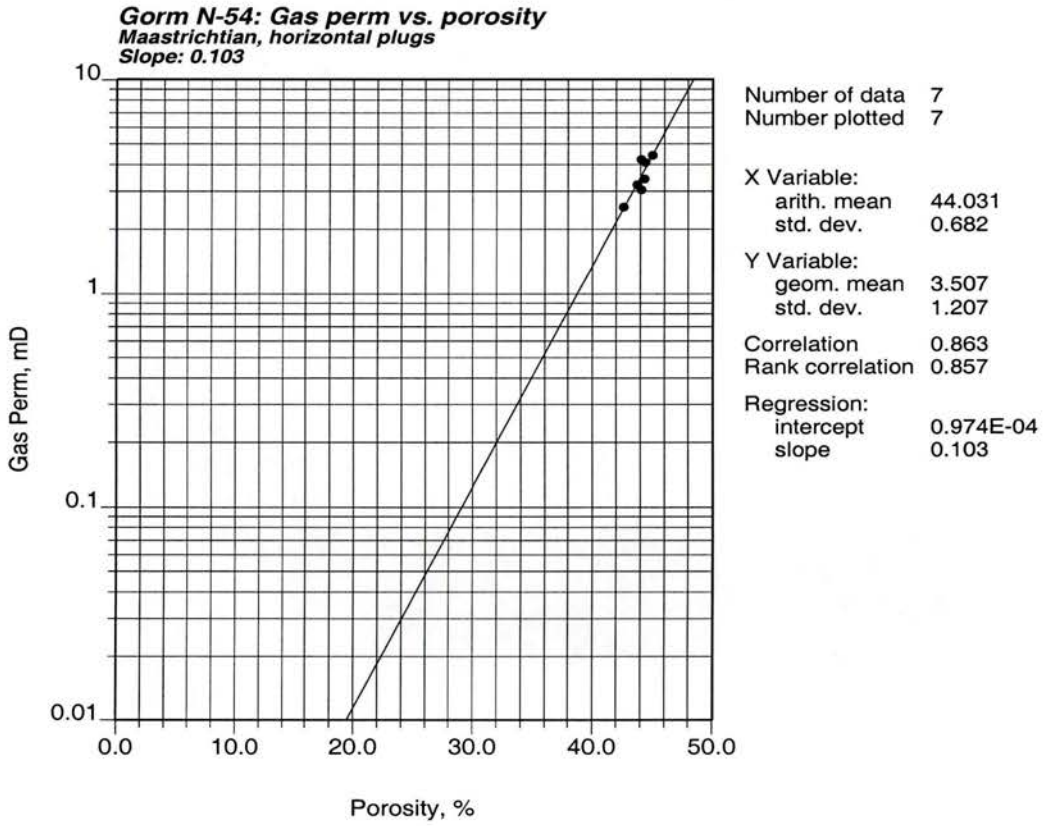
MODEL: LOG10(PERMEABILITY) = INTERCEPT + SLOPE*POROSITY + RESIDUAL

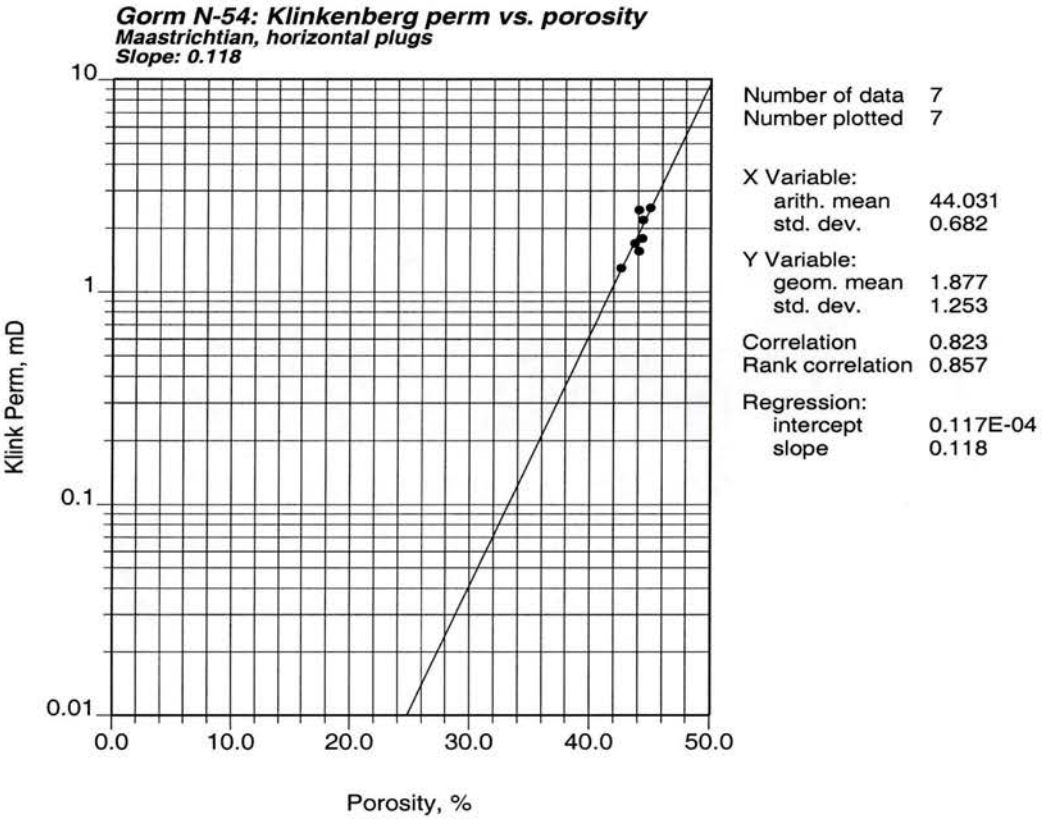
DEGREES OF FREEDOM	:	5	
COEFFICIENT OF DETERMINATION	:	0.677	
STANDARD ERROR ON THE REGRESSION	:	0.066	log(mD)
ESTIMATED INTERCEPT	:	-4.932	log(mD)
ESTIMATED STANDARD ERROR ON INTERCEPT	:	1.607	log(mD)
ESTIMATED SLOPE	:	0.11822	log(mD)/%
ESTIMATED STANDARD ERROR ON SLOPE	:	0.03650	log(mD)/%

PLEASE REMARK THAT THE REGRESSION STATISTICS PERTAIN TO LOG PERMEABILITY VALUES.
THE COEFFICIENT OF DETERMINATION GIVES THE FRACTION AF THE TOTAL VARIATION SQUARED
WHICH IS EXPLAINED BY THE MODEL.
THE STANDARD ERROR ON THE REGRESSION GIVES THE MEAN 1 SIGMA ERROR ON THE LOG
PERMEABILITY ESTIMATES.

CROSSPOLT OF POROSITY VS. GAS PERMEABILITY

WELL: GORM N-54
CORE: 1





5.2 Plug description

The plug description sheet is made in accordance with the description system given in:
Crabtree, B., Fritsen, A., Mandzuich, K., Moe, Aa., Rasmussen, F.O., Siemers, T. Søiland, G. & Tirsgaard, H., 1996: Description and Classification of Chalks – North Sea Central Graben. Joint Chalk Research Phase IV, July 1996. Norwegian Petroleum Directorate (NPD), Stavanger.

The following additional abbreviations are intended to be used in the comment column of the plug description sheet:

- Rock colour

blk	=	black
br	=	brown
gn	=	green
gy	=	grey
ol	=	olive
rd	=	red
wh	=	white
owh	=	off-white
vl-	=	very light
l-	=	light, e.g. lgy = light grey
ml-	=	medium light
m-	=	medium
md-	=	medium dark
d-	=	dark
-sh	=	-ish, e.g. brsh = brownish
var	=	varicoloured

- Miscellaneous

amp	=	amplitude of stylolite
art	=	artificial(-ly)
art F	=	artificially induced fracture
bio tex	=	bioturbate texture
Btn	=	thin-bedded
Cl	=	low consolidation
Cm	=	medium consolidation
Chi	=	high degree of consolidation
Ggl	=	glauconite grains
GIn	=	*Inoceramus* fragments
Gph	=	phosphorite grains
ids	=	indistinct(-ly)
ira	=	insoluble residue accumulation
leo	=	leopard structure
mic	=	micro
mic S	=	microstylolite, almost invisible with the naked eye
mou	=	mould(-s) from Gsk
mot	=	mottled
rep	=	replaced by
S	=	stylolite
slg	=	slight(-ly)
Ss	=	solution seam
Ssh	=	high density of solution seams
Ssl	=	low density of solution seams
TCh	=	*Chondrites* trace fossil
TPl	=	*Planolites* trace fossil
TTe	=	*Teichichnus* trace fossil
TTh	=	*Thalassinoides* trace fossil
TTr	=	*Trichichnus* trace fossil
TZo	=	*Zoophycos* trace fossil

JCR plug description scheme

Well: N-54 | Field: Gorm | Sheet no.: 1 | Geologist: NiS

Plug size Ø = 1.5"

Plug no.	Core depth ft.	Lithotype	M 1	Mf 2	Mc 3	Wf 4	Wc 5	Pf 6	Pc 7	Gf 8	Gc 9	Ch 1	Arl 2	Arh 3	Gn 1	Gsh 2	Gch 3	Gsk 4	Gct 5	Go 6	Bn 1	Btn 2	Bm 3	Btk 4	Ln 1	Lpl 2	Lun 3	Lx 4	Lg 5
			Depositional fabric: Rock type									Composition: Matrix			Composition: Grains						Stratification: Bedding				Stratification: Lamination				
1	8217.17	MaMu	1									1					3				1				1				
2	8221.50	MaMu	1									1					3				1				1				
3	8225.33	MaMu	1									1					3				1				1				
4	8229.33	MaMu	1									1			1						1				1				
5	8233.25	MaMu	1									1					3				1				1				
6	8237.17	MaMu	1									1			1						1				1				
7	8240.58	MaMu	1									1						4			1				1				

Plug no.	Dn 1	Dfl 2	Dfh 3	Dcl 4	Dch 5	Ds 6	Tn 1	Tl 2	Tm 3	Th 4	Hvs 1	Hs 2	Hm 3	Hh 4	Hvh 5	Sn 1	Sl 2	Sm 3	Sh 4	Mn 1	Mca 2	Mpy 3	Mdo 4	Msi 5	Mo 6	Fn 1	Fo 2	Fm 3	Fhl 4	Fhh 5	Fs 6	Plug no.	Comments
	Deformation structures						Bioturbation: Trace fossils				Hardness					Stylolites				Secondary minerals						Fractures							
1	1						1				1						2			1										5		1	owh, 1S, biotex, artF
2	1								3		1						2			1										5		2	owh, 1micS, artF
3	1								3		1					1				1										5		3	owh, biotex
4	1								3		1								4	1										5		4	owh, 4micS
5	1								3		1							3		1									4			5	owh, 2micS, artF
6	1							2			1					1				1										5		6	owh
7	1						1				1						2			1									4			7	owh, 1micS, Ss