DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2001/10

Speciel Core Analysis For GEO

Preparation of 54 mm plugs from Tyra

Christian Høier and Kirsten Fries

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
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GEUS

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1. Introduction

By request of GEO, GEUS Core Laboratory has carried out conventional core analysis on 54mm plugs and plug trims from the well TEC-1 and TWC-2 in the Tyra field.

The experimental programme was specified by Ms. Helle F. Christensen. The following analytical programme has been carried out:

- Cleaning of 54 mm plugs and plug trims
- Fluid saturation measurements on plug trims
- Porosity and grain density on 54 mm plugs and plug trims
- Saturation of 54 mm plugs with brine and oil
- Fluid saturation measurements on 54 mm plugs

Several preliminary data have been forwarded to GEO in the time period September 2000 - January 2001.

2. Sampling and analytical procedure

GEUS Core Laboratory received a total of 6 pcs. 54 mm plugs to be prepared with a chosen water saturation and 10 plug trims to be determine for porosity and grain density. After preparation, the 54 mm plugs were delivered to GEO for experiments. Later 7 pcs. 54 mm plugs were received for fluid saturation measurements.

2.1 Hot Soxhlet cleaning

The plugs were cleaned in methanol and toluene and then dried at 110 °C.

2.2 Porosity and grain density

He-porosity and grain density was measured on plug trims and 54 mm plugs

2.3 Saturation with brine and oil

The plugs were saturated using the following steps:

- 100 % saturation with diluted brine or tap water using a vacuum technique.
- A predetermined water saturation was reached, by leaving the plugs at room temperature for 3 – 5 days and allow the brine/water to evaporate.
- Air was replaced with oil by mounting the plugs in core holders and flooding them with oil. Care was taken not to produce any water during the flooding with oil.

2.4 Fluid saturation

The following densities were used for the calculation of fluid saturation for the plug trims:
1.019 g/ml for the brine and 0.85g/ml for the oil.

The determination of fluid saturation of the 54 mm plugs after completion of the experiment at GEO was more difficult due to the poor condition of the plugs, which made it impossible to measure the pore and bulk volume. The initially bulk volume was therefor corrected for the compaction measured at GEO and from the grain loss when the plugs were unpacked at GEUS Core Laboratory. Two different methods were used.

Method 1 - Using the final porosity ($Ø_c$) of the samples after compaction measured by GEO.

The bulk and pore volume corrected for compaction and grain loss can be calculated as:

$$BV_c = (BV_i - X) \cdot F_G \quad ; \quad X = \frac{Ø_c \cdot BV_i - 100 \cdot PV_i}{Ø_c - 100} \quad , \quad F_G = \frac{\sigma_A}{\sigma_B}$$

$$PV_c = BV_c \cdot Ø_c$$

Hvor,

BV_c = Bulk volume corrected for compaction and grain loss
BV_i = Initially bulk volume
PV_c = Pore volume corrected for compaction and grain loss
PV_i = Initially pore volume
X = Bulk volume reduction due to compaction
F_G = Grain loss factor

$\varnothing_c$ = Compacted porosity
$\varnothing_i$ = Initially porosity
σ_A = Dry weight of sample AFTER experiment
σ_B = Dry weight of sample BEFORE experiment

The following densities were used for the calculation of fluid saturation for the 54 mm plug: 1.018 g/ml for the brine and 0.765 g/ml for the oil.

Method 2 – Using mass balance and assuming no gas saturation.

The compacted pore and bulk volume (grain loss is included in the measurement of PV_c) is:

$$PV_c = E_w + \frac{(\sigma_{wet} - \sigma_{dry}) - E_w \cdot \delta_w}{\delta_o}$$

$$BV_c = BV_i - (PV_i - PV_c)$$

hvor,

BV_c = Bulk volume corrected for compaction and grain loss
BV_i = Initially bulk volume
PV_c = Pore volume corrected for compaction and grain loss
PV_i = Initially pore volume
E_w = Extracted water from Dean-stark
σ_{wet} = Wet weight of plug
σ_{dry} = Dry weight of plug
δ_w = Density of water
δ_o = Density of oil

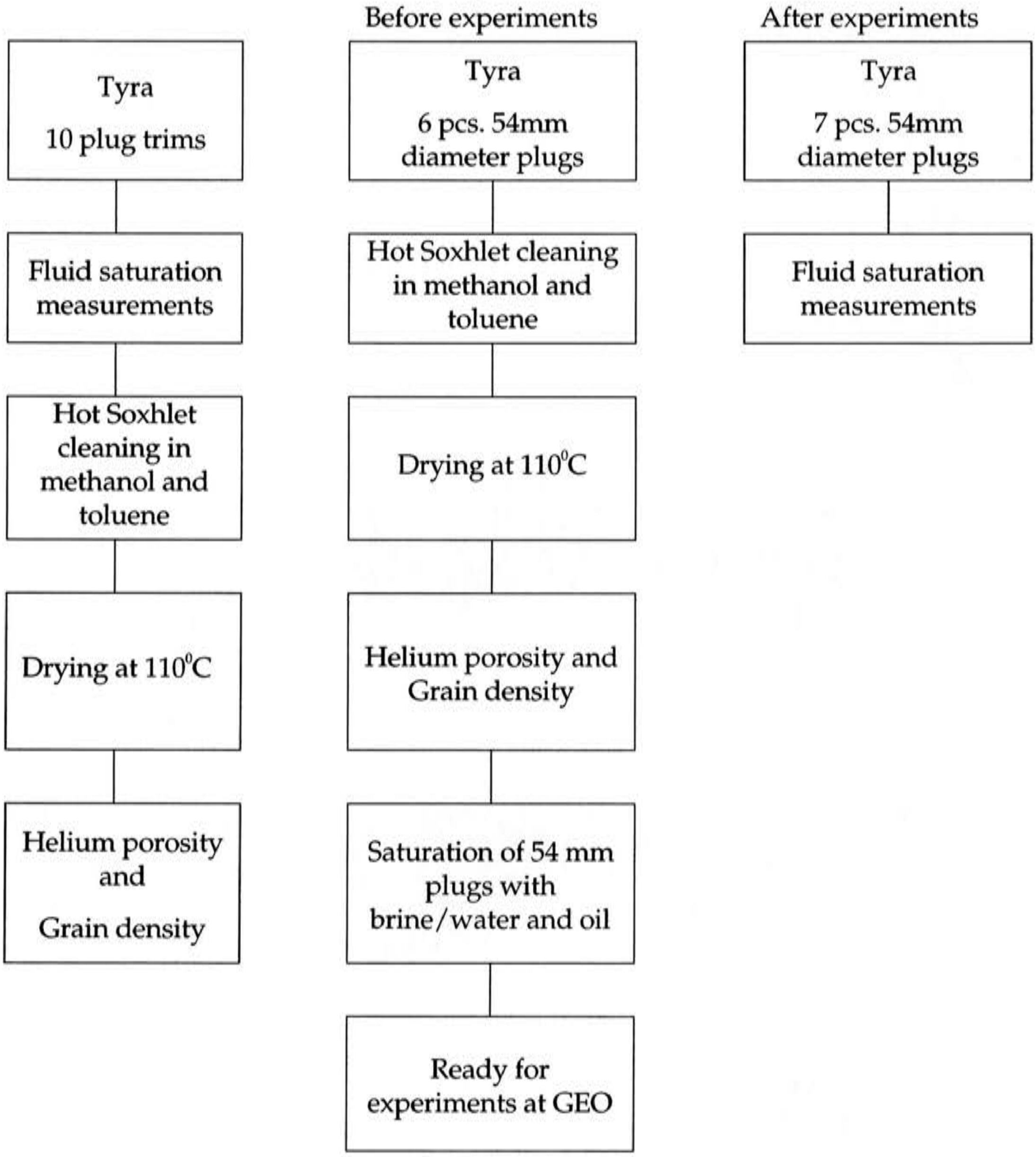
The following densities were used for the calculation of fluid saturation for the 54 mm plug: 1.018 g/ml for the brine and 0.765 g/ml for the oil.

2.5 Insoluble residue and amount of quartz in the residue

The calcite is removed using a buffered acetic acid at pH 4.5. This mild dissolution of the calcite is carried out in order to avoid dissolution of non – calcite minerals.

X – ray diffraction (XRD) is carried out on randomly oriented specimens using a Philips 1050 goniometer with Co - Kα radiation (pulse – high selection and Fe – filter).
The amount of quartz in the residues is determined using quartz 4.5 - 45 µm in size as a standard.

3. Flow chart of the analytical procedure



4. Analytical methods

The following is a short description of the methods used by the GEUS Core 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, 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 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.

4.3 Fluid saturation determination

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.

4.6 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 the GEUS Core Laboratory.

Measurement	Precision
Grain density	0.003 g/cc
Porosity	0.1 porosity-%

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

Table 5.1 below is a listing of data for the 54 mm plugs with the prepared water saturation.

Plug	Depth feet	Porosity %	Grain density g/ml	Dry weight g	Bulk vol. ml	Pore vol. ml	Liquid density g/ml	Wet weight g	Sat. %	Water Sat. ml
lab3	7066.33	38.15	2.703	409.70	245.10	93.51	0.765	479.77	98.0	0.0
lab4	7073.17	38.72	2.703	343.27	207.24	80.24	0.997	346.82	4.4	3.6
lab5	7697.75	42.80	2.705	381.20	246.38	105.45	0.997	385.80	4.4	4.6
lab8	7690.25	41.53	2.706	390.10	246.59	102.41	0.997	392.25	2.1	2.2
lab9	7688.83	39.27	2.704	331.15	201.65	79.18	1.018	342.89	14.6	11.5
lab10	7689.25	38.52	2.702	411.40	247.63	95.38	1.018	440.17	29.6	28.3

Table 5.2 below is a listing of the fluid saturation for the 54 mm plugs after compaction at GEO. The pore and bulk volume are calculated using porosity's from GEO (method 1), see section 2.4.

Plug	Depth feet	Porosity %	Grain density g/ml	Dry weight g	Bulk volume ml	Pore volume ml	Extracted water ml	Wet weight g	Water sat. %	Oil Sat. %	Gas Sat. %
lab3	7066.33	32.0	2.705	365.74	199.01	63.68	50.5	434.33	79.9	34.5	-14.4
lab4	7073.17	35.5	2.706	317.05	181.86	64.56	47.0	381.34	73.3	32.6	-5.9
lab5	7697.75	40.3	2.705	346.78	214.75	86.54	69.0	429.74	80.3	18.4	1.3
lab7	7699.75	-	-	382.82	-	-	0.5	443.44	-	-	-
lab8	7690.25	39.7	2.707	375.6	230.22	91.40	71.0	464.14	78.3	22.5	-0.7
lab9	7688.83	35.5	2.711	317.95	182.31	64.72	49.5	379.69	77.1	22.2	0.8
lab10	7689.25	34.8	2.706	389.9	221.31	77.02	55.9	471.62	73.1	41.4	-14.5

Table 5.3 below is a listing of the fluid saturation for the 54 mm plugs after compaction at GEO. The pore and bulk volume are calculated using mass balance and assuming no gas saturation (method 2).

Plug	Depth feet	Porosity %	Grain density g/ml	Dry weight g	Bulk volume ml	Pore volume ml	Extracted water ml	Wet weight g	Water sat. %	Oil Sat. %	Gas Sat. %
lab3	7066.33	32.5	2.705	365.74	224.5	73.0	50.5	434.33	69.7	30.1	0.2
lab4	7073.17	35.0	2.706	317.05	195.5	68.5	47.0	381.34	69.2	30.7	0.1
lab5	7697.75	37.8	2.705	346.78	226.6	85.6	69.0	429.74	81.2	18.6	0.2
lab7	7699.75	-	-	382.82	-	79.1	0.5	443.44	-	-	-
lab8	7690.25	39.0	2.707	375.6	236.4	92.3	71.0	464.14	77.6	22.3	0.1
lab9	7688.83	34.4	2.711	317.95	186.8	64.3	49.5	379.69	77.6	22.3	0.1
lab10	7689.25	36.7	2.706	389.9	240.6	88.3	55.9	471.62	63.8	36.1	0.1

Table 5.4 below is a listing of conventional core analysis data on plug trims.

Plug trims	Depth feet	Porosity %	Gr.Dens. g/ml	Water sat. %	Oil sat. %	Gas sat. %
1	7168.50	36.13	2.714	1.4	21.7	76.9
2	7064.42	37.93	2.710	0.0	24.6	75.4
3	7066.33	37.37	2.724	0.0	53.7	46.3
4	7073.17	38.55	2.704	0.3	23.1	76.6
5	7697.75	42.86	2.708	0.3	17.8	81.9
6	7696.92	29.00	2.712	0.0	80.2	19.8
7	7699.75	39.10	2.704	0.0	18.1	81.9
8	7690.25	39.74	2.722	0.0	26.9	73.1
9	7688.83	38.84	2.702	0.0	27.2	72.8
10	7689.25	38.27	2.708	0.3	28.4	71.3

Table 5.5 below is a listing of insoluble residue and amount of quartz in the residue.

Well:	**Plug no.**	**Well.**	**Depth** feet	**Insoluble residue** %	**Amount of quartz in the residue** %
Tyra TEC-1/TWC-2	1	TEC-1	7168.50	4	57
Tyra TEC-1/TWC-2	2	TEC-1	7064.42	4	51
Tyra TEC-1/TWC-2	3	TEC-1	7066.33	4	57
Tyra TEC-1/TWC-2	4	TEC-1	7073.17	3	48
Tyra TEC-1/TWC-2	5	TWC-1	7697.75	2	34
Tyra TEC-1/TWC-2	6	TWC-1	7696.92	2	31
Tyra TEC-1/TWC-2	7	TWC-1	7699.75	1	29
Tyra TEC-1/TWC-2	8	TWC-1	7690.25	3	15
Tyra TEC-1/TWC-2	9	TWC-1	7688.83	1	29
Tyra TEC-1/TWC-2	10	TWC-1	7689.25	1	35