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DGU Service report no. 14 • 1991

CONVENTIONAL CORE ANALYSIS FOR ORKUSTOFNUN

Well: Ær - 4

Ministry of the Environment
Geological Survey of Denmark

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Core Analysis Laboratory

By Niels Springer

CONFIDENTIAL Copy number: 2

Ministry of the Environment
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1 Introduction

By request of Orkustofnun, DGU Core Analysis Laboratory has carried out conventional core analysis on material from the well Ær-4, onshore Iceland.

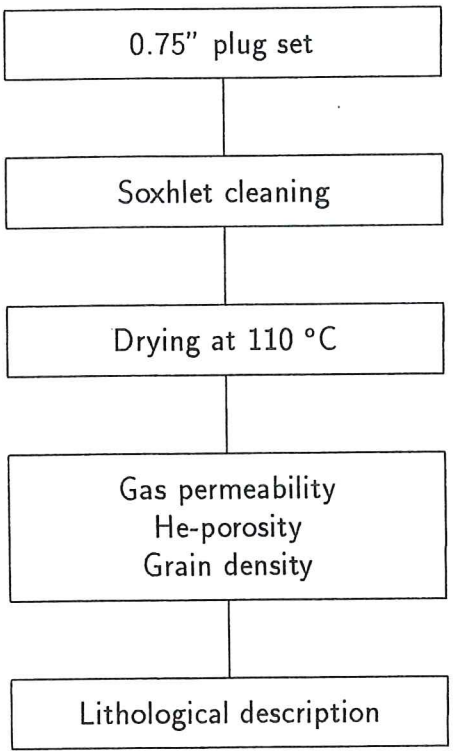
The samples were delivered by Mr. Jens Henriksen, DGU Geochemical Department. A preliminary copy of the report was printed on 09.12.1991.

2 Sample handling and analytical procedure

The laboratory received 11 plugs of siltstone/sandstone for routine analysis. The plugs were trimmed to a length of approx. 2.8 cm, cleaned in methanol and dried at 110 °C. The plugs were then analyzed for gas permeability, porosity and grain density. Finally a short lithological description was carried out.

Because of the small diameter of the plugs, 0.75 inches, a special sleeve had to be prepared to make the samples fit into a standard 1 inch core holder for permeability measurement.

3 Schematic outline of the analytical procedure



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, 1960).

4.1 Conventional cleaning and drying

The plug are drilled and trimmed to a size of 1" diameter and $1\frac{1}{2}$" length. The samples are then placed in a Soxhlet extractor, which continously 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 customer.

4.2 Cold flush cleaning and saturation

Samples selected for special core analysis may be cleaned using the cold flush miscible liquids cleaning technique. Depending on the final saturation the cleaning sequence is the following:

$$toluene \rightarrow methanol \rightarrow toluene \rightarrow lab.\ oil$$
$$toluene \rightarrow methanol \rightarrow formation\ water$$

The plug sample is mounted in a Hassler core holder and a confining pressure of 400 psi applied. The liquids are flushed through the sample. Each step in a cleaning cycle may require a liquid throughput of 5-20 PV's, or until the effluent is free of salt and colourless. The sample is then transferred to a pressure pot completely filled with the saturating liquid and a pressure of 1000 psi applied for a period of 2-3 days.

4.3 Substitution saturation

Natural state or well preserved core samples can be saturated with laboratory oil or crude without being subjected to cleaning liquids. The core sample is confined in a Hassler cell at 400 psi, placed in an oven and heated to reservoir temperature. Dead oil is displaced out of the sample by flowing laboratory oil or crude through the plug. Many pore volumes, often more than 100, and a long period of time, especially for low permeability samples, is required before the substitution is completed. This is best seen for a laboratory oil; the effluent should be colourless or only slightly coloured when saturation is stopped.

4.4 Gas permeability

The plug is mounted in a Hassler core holder, and a confining pressure of 250 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 reported gas permeabilities are the mean of at least 2 measurements taken at different flow rates on a digital gas permeameter. The permeameter readings are checked regularly by routine measurement of permeable steel reference plugs.

4.5 Klinkenberg permeability

The plug is mounted in a Hassler core holder, and a confining pressure of 250 psi is applied to the sleeve. A nitrogen gas pressure is applied at the upstream end of the plug, and the downstream pressure is regulated until a suitable flow is obtained. When a steady state is reached, the upstream pressure, the differential pressure across the plug and the flow reading is recorded.

If the specific permeability to gas for a given plug is greater than approx. 0.1 mD the permeability measurement is performed at 3 different values of the upstream pressure, usually 3, 5 and 8 atm. (abs.). The differential pressure is kept approx. constant in order to maintain a similar flow regime during the 3 measurements. A linear regression of permeability on inverse mean pressure is performed, and the intercept on the permeability axis is the Klinkenberg corrected gas permeability. To ensure compatibility with data sets which do not include Klinkenberg corrected gas permeability, a permeability value pertaining to a mean pressure of 1.5 atm. (abs.) is calculated from regression coefficients. If requested, this value is reported as "1.5 PM permeability" in the core analysis tabulation.

If the specific permeability to gas for a given plug is less than approx. 0.1 mD the permeability measurement is only performed once at an upstream pressure of 2 atm. (abs.) and a differential pressure of 1 atm. The resulting value for specific permeability to air thus pertains to a mean pressure of 1.5 atm. (abs.). The performance of the digital gas permeameter is checked regularly by routine measurement of permeable steel reference plugs.

4.6 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.

4.7 Archimedes porosity

Samples that are saturated to 100 % with a liquid can have their bulk volume determined by Archimedes test, i.e. by submersion in a jar containing the saturating liquid and weighing of the buoyancy. If the sample grain density is known (e.g. from a He-porosity measurement) or can be estimated with good precision, the sample pore volume and porosity can be calculated.

4.8 Fluid saturation determination

The water content of a plug is extracted by Dean Stark destillation 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 decribed in section 4.5.

The calculation of fluid saturation presumes that the oil gravity is known. If it is unknown, a value is assumed in the final calculation, cf. the core analysis tabulation in section I. The percentage of the plug pore volume which is not occupied by either water or oil is the gas saturation.

4.9 Precision of analytical data

The table below gives the precision (= reproducibility) at the 68% level of confidence ($\pm$ 1 standard deviation) for routine core analysis measurements performed at the DGU Core Analysis Laboratory.

Measurement	Range, mD	Precision
Grain density		0.003 g/cc
Porosity		0.1 porosity-%
Permeability: (Klinkenberg)	0.01 – 0.1 0.1 – 1 > 1	10% 2% 1%
Permeability: (Conventional)	0.001 – 0.01 0.01 – 0.1 > 0.1	20% 5% 1%

5 Results

5.1 Listing of core analysis data

Ministry of the Environment
Geological Survey of Denmark

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GEOLOGICAL SURVEY OF DENMARK

CORE ANALYSIS LABORATORY

CORE ANALYSIS TABULATION

FINAL REPORT

Compiled by Niels Springer

WELL : ÆR-4

CORE :

Printed : 9-DEC-91

GENERAL INFORMATION ON THE ANALYSIS

COMPANY : ORKUSTOFNUN
DEPTH INTERVAL : 329.45 - 438.90
DEPTHS ARE MEASURED FROM
DEPTHS ARE IN METRES

LOCATION : ISLAND
CORE NO.'S :
ANALYSTS : TB
DATE : 091291

REMARKS :

1.1"

Plugs were trimmed to a length of 2.8 cm, cleaned in methanol and dried at 110°C. The listed air permeability is a conventional permeability measured using nitrogen gas.

Notice: Plugs are smaller than normal with a diameter of 0.75 inch.

ABBREVIATIONS FOR LITHOLOGICAL DESCRIPTIONS:

Rock type	chk	Chalk
	cly	Claystone
	mud	Mudstone
	slt	Siltstone
	sst	Sandstone
	cngl	Conglomerate
	htrl	Heterolith
Grain size	vf-	Very fine grained,
	f-	Fine grained, ex. fsst = fine grained sst
	m-	Medium grained
	c-	Coarse grained
	vc-	Very coarse grained
Colour	br	Brown
	gn	Green
	gy	Grey
	ol	Olive
	rd	Red
	wh	White
	vl-	Very light
	l-	Light, ex. lgy = light grey
	ml-	Medium light
	m-	Medium
	md-	Medium dark
	d-	Dark
	-sh	-ish, ex. brsh = brownish
Structures	bed	Bedding
	bio	Bioturbation
	bnd	Banding
	bur	Burrow(-s)
	cho	Chondrites
	cla	Clast(-s)
	coal	Coal/coalbearing
	crs	Crossbedding
	frg	Fragment(-s)
	ifil	Infilling
	lam	Lamina/lamination
	plt fos	Plant fossil(-s)
	pynd	Pyrite nodule(-s)
	shl	Shell fragment(-s)
	sly clv	Slaty cleavage
	sol sm	Solution seam(-s)
	spng	Sponge(-s)
	sty	Stylolite seam(-s)
	trc fos	Trace fossil(-s)
	zoo	Zoophycos

Miscellaneous	ab	Abundant
	ana	Anastomosing
	arg	Argillaceous
	brd	Broad
	ccem	Calcite cemented
	cls	Close
	cse	Coarse
	dif	Diffuse
	dk	Dark
	ds	Distinct
	fin	Fine
	fnt	Faint
	fw	Few
	grd	Graded
	hrd	Hard
	hom	Homogeneous
	ids	Indistinct
	incl	Inclusion(-s)
	ind	Indurated
	int	Intraformational
	irr	Irregular
	lge	Large
	mny	Many
	mot	Mottled
	nhom	Nearly homogeneous
	prm	Prominent
	prt	Partly
	slg	Slightly
	sme	Some
	sml	Small
	sp	Sparse
	thn	Thin
	v	Very
	w	With
	wl	Well
Fractures	FRC	Fracture
	FT FRC	Fatal fracture
	SG FRC	Significant fracture
Minerals	fsp	Feldspar
	mica	Mica flakes
	qtz	Quartz
	py	Pyrite

WELL : ÆR-4
CORE :

	SAMPLE NO.	DEPTH METER	PLUG TYPE	AIR PERM mD	POROSITY %	GRAIN DENS. g/cc	LITHOLOGY
329.5	P1	329.45	HOR	0.054	42.11	2.873	lgy cly w silty lam
?	P2	339.80	HOR	0.053	38.46	2.726	lgy-gn arg slt, lam
347.85	P3	347.77	HOR	0.036	37.86	2.649	lgy-gn silty sst
350.6	P4	350.98	HOR	0.034	40.31	2.656	lgy-gn silty sst
360.4	P5	368.58	HOR		40.11	2.730	lgn cly, brecciated
	P6	395.50	HOR	0.037	41.34	2.729	lgy-gn silty sst
	P7	404.10	HOR	0.072	36.03	2.757	lgy-gn hom fsst
	P8	411.00	HOR	0.268	40.75	2.807	lgy lam cly
	P9	415.60	HOR	0.310	38.51	2.809	lgy-gn arg slt, lam
	P10	434.70	HOR	0.061	36.00	2.840	lgy hom cly
	P11	438.90	HOR	0.027	24.26	3.000	lgy-gn diamictite

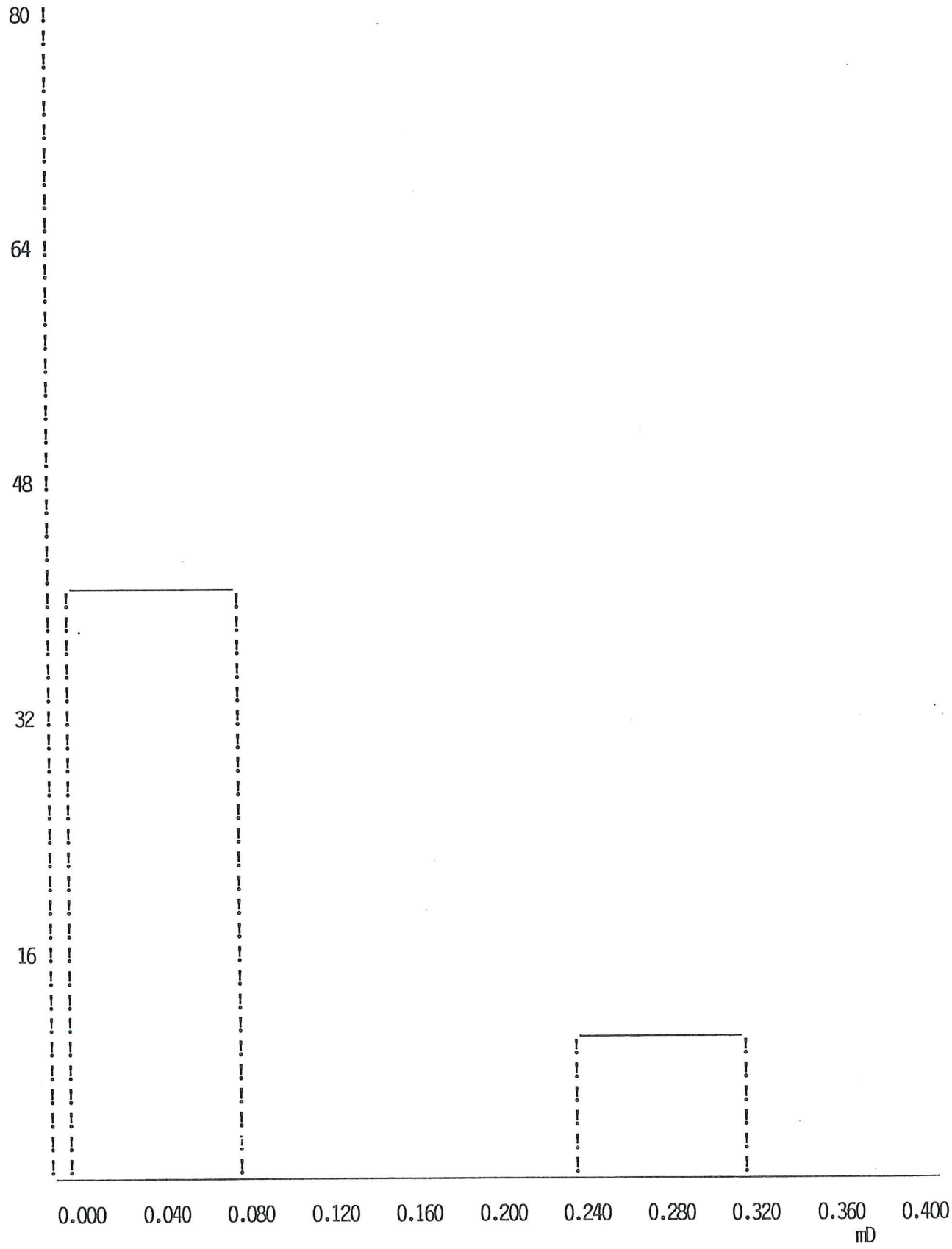
FREQUENCY PLOT

WELL : ÆR-4
CORE :

PAGE : 5

% OF SAMPLES

DISTRIBUTION OF AIR PERMEABILITY

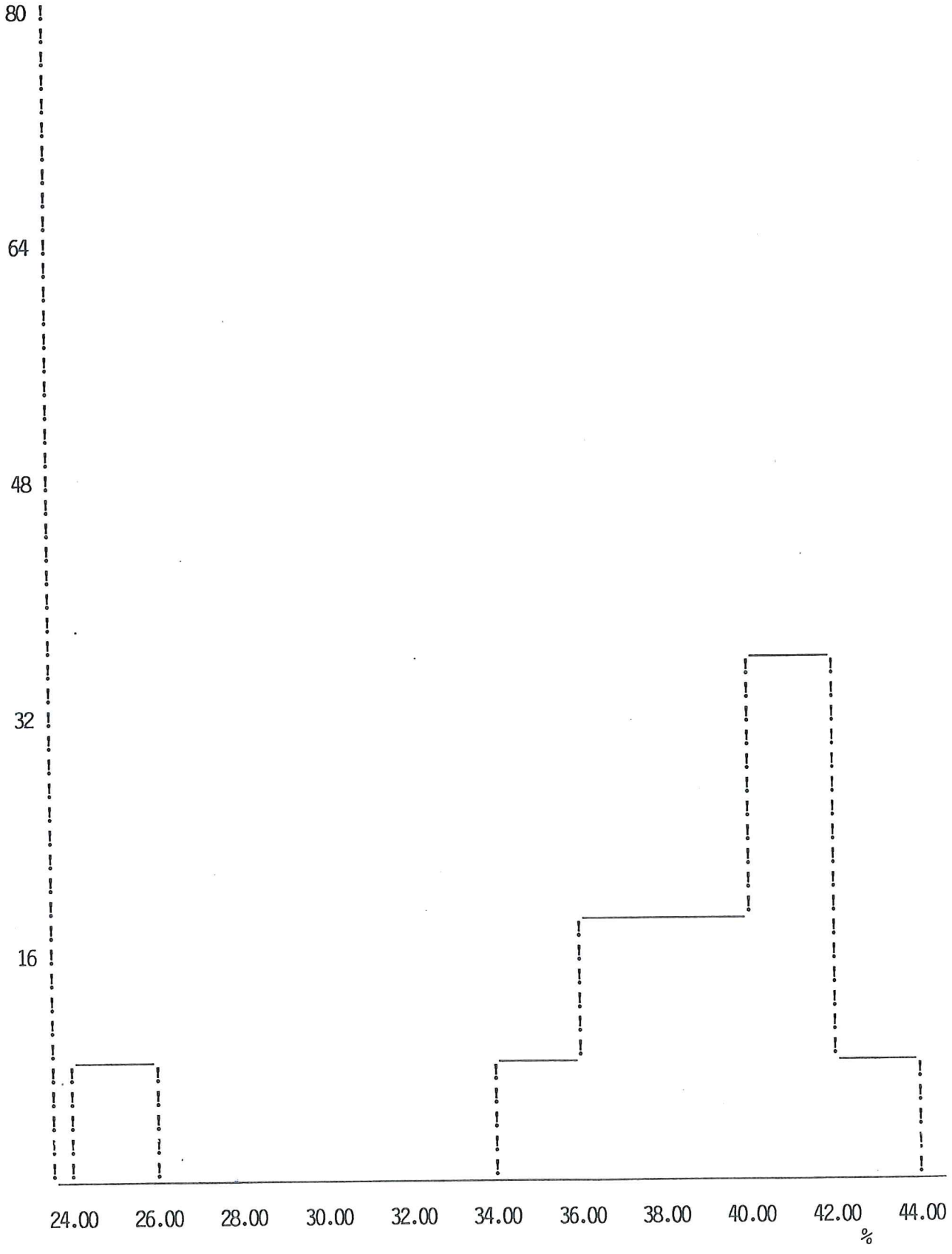


FREQUENCY PLOT

WELL : ÆR-4
CORE :

% OF SAMPLES

DISTRIBUTION OF POROSITY



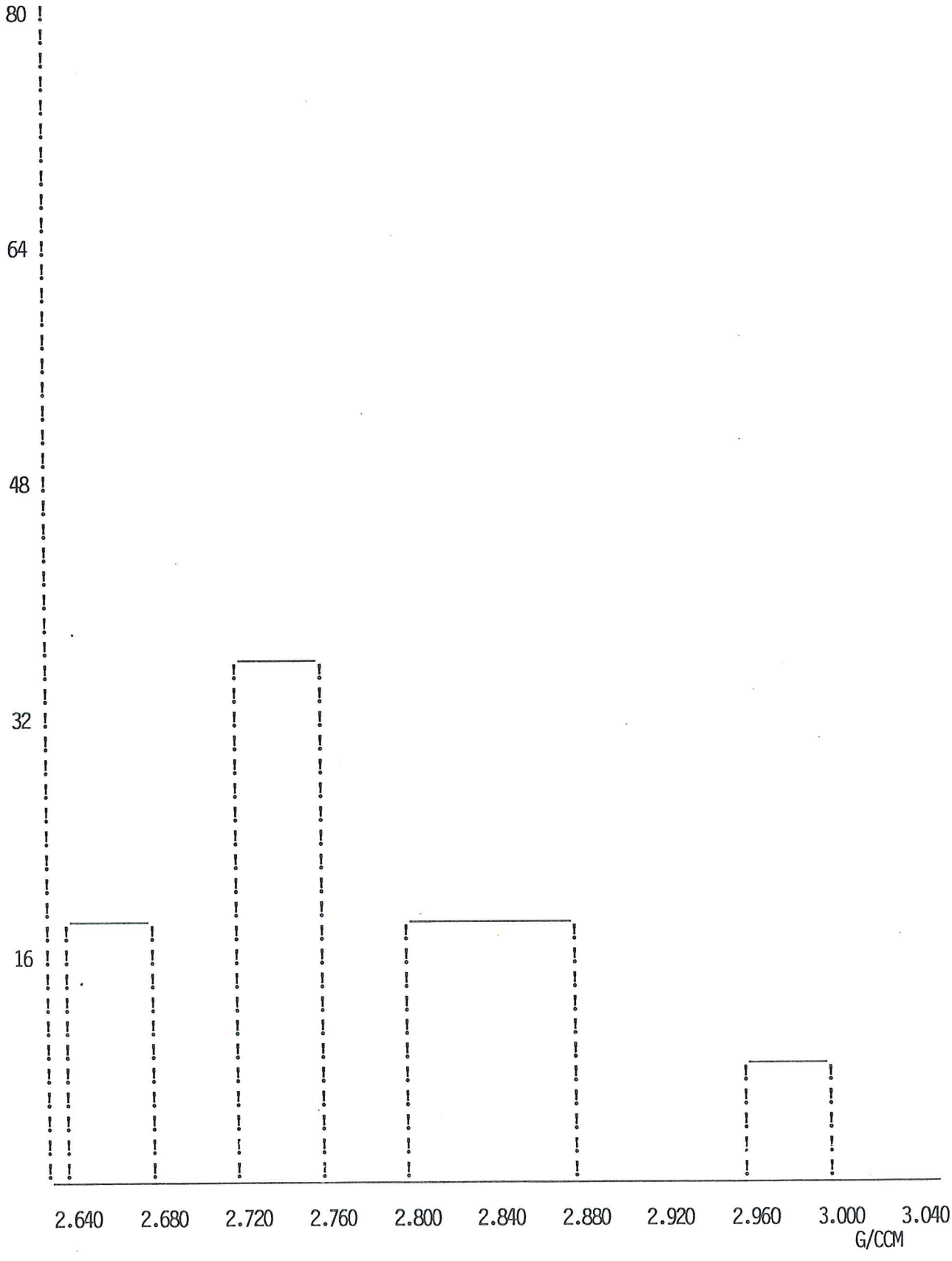
FREQUENCY PLOT

WELL : ÆR-4
CORE :

PAGE : 7

% OF SAMPLES

DISTRIBUTION OF GRAIN DENSITY



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

MODEL (LINEAR FITTING) : LOG10(PERMEABILITY) = INTERCEPT + SLOPE*(POROSITY - MEAN(POROSITY))

---------- RESULTS CONCERNING THE ANALYSIS ----------

NUMBER OF SAMPLES		:	10
ESTIMATED VARIANCE ON THE REGRESSION		:	0.134
DEGREES OF FREEDOM		:	8
PERMEABILITY:			
GEOMETRIC AVERAGE	(md)	:	0.06
ARITHMETRIC AVERAGE	(md)	:	0.10
HARMONIC AVERAGE	(md)	:	0.05
ESTIMATED INTERCEPT (LOG GEOM. AVE.)		:	-1.189
ESTIMATED VARIANCE ON INTERCEPT		:	0.01341
ESTIMATED SLOPE		:	0.02352
ESTIMATED VARIANCE ON SLOPE		:	0.00057
ESTIMATED MEAN POROSITY %		:	37.56
ESTIMATED VARIANCE ON POROSITY		:	26.24360
CORRELATION COEFFICIENT		:	0.330

CROSSPLOT OF POROSITY VS. AIR PERMEABILITY WELL : ÆR-4 PAGE : 9
CORE :