DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/16

Completion report Billegrav-2 well (DGU 248.61) southern Bornholm

Part 3: Results of core plug analysis

Niels H. Schovsbo

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

G E U S

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/16

Completion report Billegrav-2 well (DGU 248.61) southern Bornholm

Part 3: Results of core plug analysis

Niels H. Schovsbo

Released 31.05.2017

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

GEUS

Table of Contents

1. Introduction

The well 'DGU 248.61' (informally referred to as the Billegrav-2 well) was drilled as part of a shallow drilling campaign conducted by GEUS on southern Bornholm in August 2010 (Figure 1). The aim was to obtain fresh core material for stratigraphical and geochemical studies of the Lower Palaeozoic shales (Schovsbo et al. 2011).

This report is part of a study program on the Billegrav-2 well and summarizes laboratory measurements made on 30 core samples. Other reports related to the Billegrav-2 wells are: 'Results of down hole logs and core scanning' (Schovsbo 2011a), 'Review of the Billegrav-1 and Skelbro-1 wells' (Schovsbo 2011b), 'Lithological and stratigraphical description including geochemical analysis' (Nielsen & Schovsbo 2012) and 'Fracture distribution and mineralogy' (Jakobsen & Schovsbo 2012).

The 30 core plug samples were subjected to various analyses including: He- and Hg-porosity measurements, Hg-injection measurements, specific surface measurements (BET), TOC analysis, Rock Eval determinations, mineralogical (quantitative and semi-quantitative) evaluations, determination of rock strength and deformation properties and measurements of Vp and Vs velocities in three directions relative to the bedding plane. Not all analysis types were preformed on all samples.

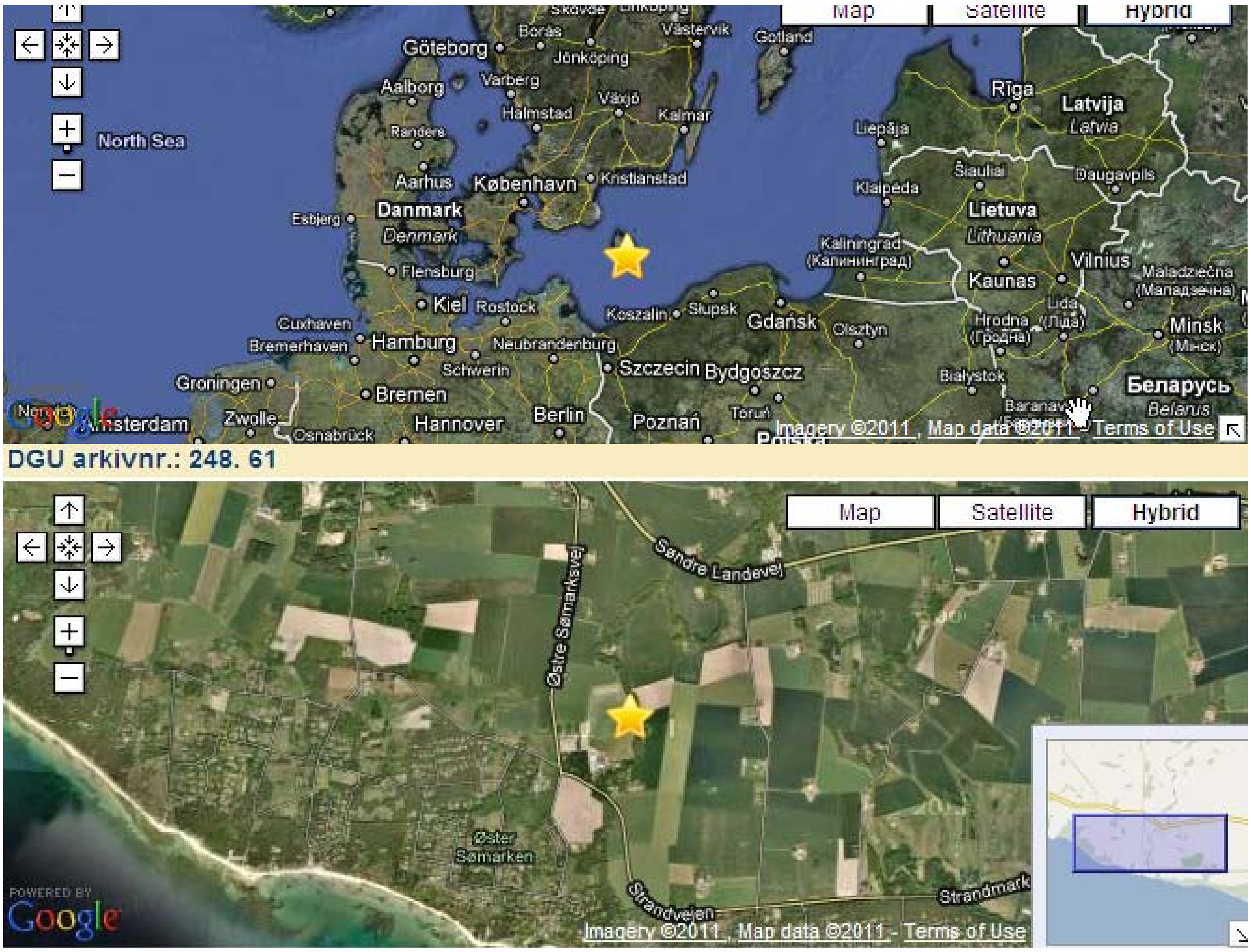


Figure 1. Location of the Billegrav-2 well, southern Bornholm, Denmark. The well location is shown with a yellow star.

2. Samples

A total of 30 core samples were investigated. 21 of the samples were selected at the drill site and sealed in PVC coated aluminium foil bags or preserved in air tight water filled containers (Table 1). Ni additional samples were picked from the core during the core description in order to cover the full range in lithologies present in the core (Table 1).

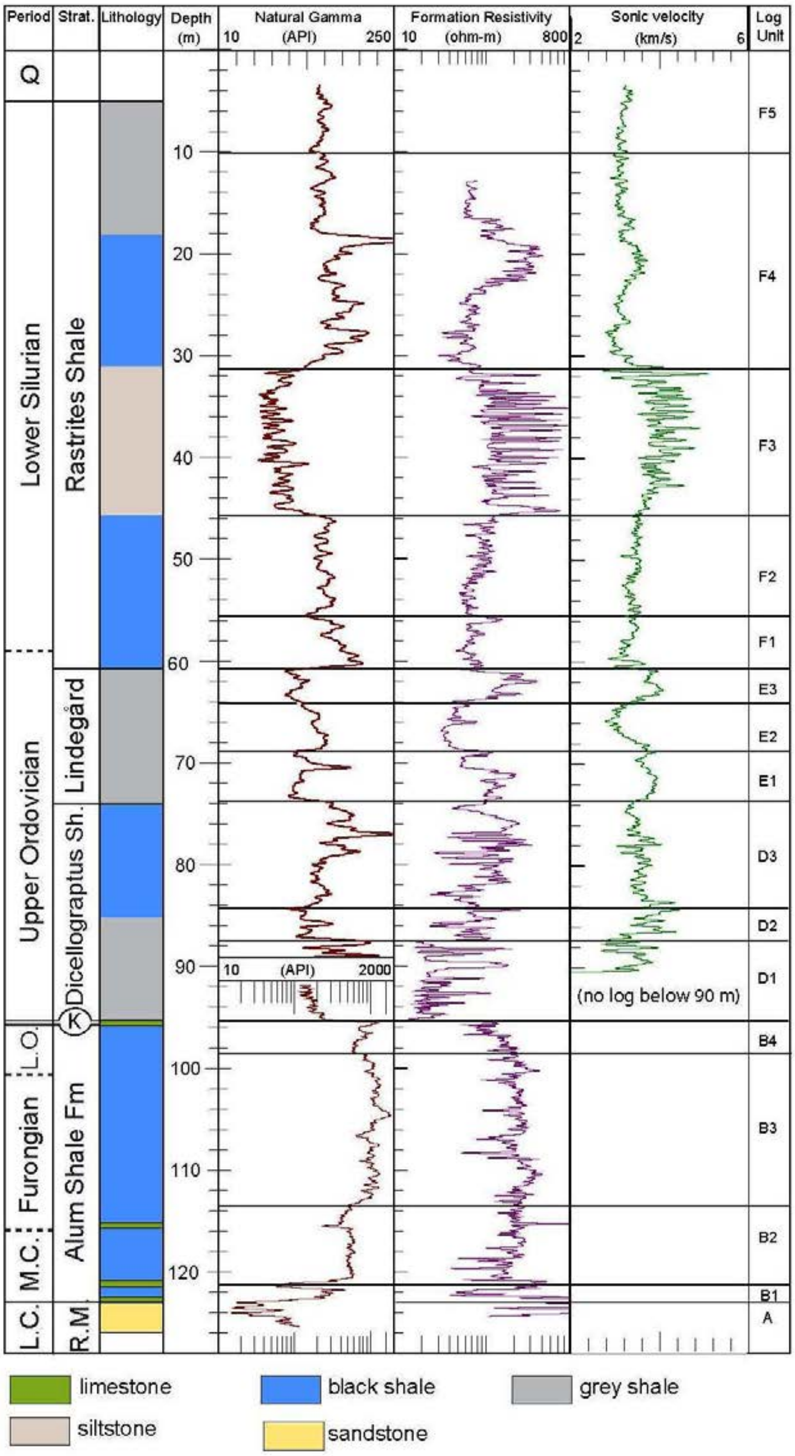


Figure 2. Gamma ray log, di-pole sonic log and formation resistivity log in the Billegrav-2 well. Lithology and stratigraphical division is after Schovsbo et al. (2011).

Table 1. Samples from the Billegrav-2 core. Each sample represents a full core section about 7-10 cm long. For some analysis subsamples were picked from the original sample. The preserved samples were selected just after drilling and preserved at the drill site.

Sample #	Formation	Unit	Top m	Base M	Preserved in foil bags	Preserved in water	Not preserved
1	Rastrites	F5	5.18	5.28	1		
2	Rastrites	F4	10.63	10.70	1		
3	Rastrites	F4	14.90	14.97	1		
4	Rastrites	F4	19.87	19.95	1		
5	Rastrites	F4	23.13	23.18			1
6	Rastrites	F4	24.80	24.90	1		
7	Rastrites	F4	29.90	29.99	1		
8	Rastrites	F3	35.00	35.10	1		
9	Rastrites	F3	41.02	41.15	1		
10	Rastrites	F3	42.65	42.74			1
11	Rastrites	F3	44.90	45.00	1		
12	Rastrites	F2	50.82	50.90			1
13	Rastrites	F1	56.52	56.60			1
14	Lindegård	E3	61.30	61.37	1		
15	Lindegård	E1	69.39	69.53	1		
16	Dicellogp.	D3	74.90	74.99	1		
17	Dicellogp.	D3	76.51	76.89		1	
18	Dicellogp.	D3	80.40	80.47	1		
19	Dicellogp.	D2	86.62	86.68			1
20	Dicellogp.	D1	93.40	93.47			1
21	Alum	B4	96.69	96.76			1
22	Alum	B3	98.81	98.90	1		
23	Alum	B3	101.50	101.57		1	
24	Alum	B3	102.87	102.93			1
25	Alum	B3	105.80	105.90	1		
26	Alum	B3	110.90	110.98	1		
27	Alum	B2	113.30	113.35			1
28	Alum	B2	115.65	115.75	1		
29	Alum	B2	116.78	116.86		1	
30	Alum	B2	119.80	119.90	1		

3. Porosity, Hg-injection and BET measurements

3.1. He-porosity

Methodology

He-porosity measurements were performed at GEUS core laboratory. The measurements were made at room conditions in an unconfined sample cup. The samples were dried at 60 ºC until constant weight. The method uses Boyle's Law to determine sample grain volume in a double cell He-porosimeter with digital readout. Bulk volume was measured by submersion of the sample in a mercury bath using Archimedes principle. The porosity was obtained by subtraction of the measured grain volume from the measured bulk volume. Grain density was calculated from the grain volume measurement and from the weight of the cleaned and dried sample.

The He-porosimeter was calibrated using a set of steel plugs (Core Laboratories volume reference plug set) before the measurement of the plug samples was initiated. The bulk volume apparatus was checked using a steel plug with known volume.

Table 2 gives the precision (= reproducibility) at the 68% level of confidence (+/- 1 standard deviation). For more detailed description of methods, instrumentation and principles of calculation see API recommended practice for core analysis procedure (API RP 40. 2nd ed. 1998).

Measurement	Range [mD]	Precision
Grain density		0.003 g/cc
Porosity		0.15 porosity-%

Table 2. Reproducibility at the 68% level of confidence (+/- 1 standard deviation) on the analytical setup used at GEUS core laboratory.

As part of methodology development the sample were re-measured for its He-porosity. For the second analytical run the samples were dried at 100 ºC in 5 days. The measured He-porosities of the samples that were dried at 100 ºC were within uncertainty of the He-porosity measured after drying the samples at 60 ºC.

Time allowed for the sample to equilibrate in the He-porosimeter was generally less than 30 minutes and typically 15 minutes. Long equilibration times (>hours) were avoided in order to reduce possible condensation effects of He into the pores.

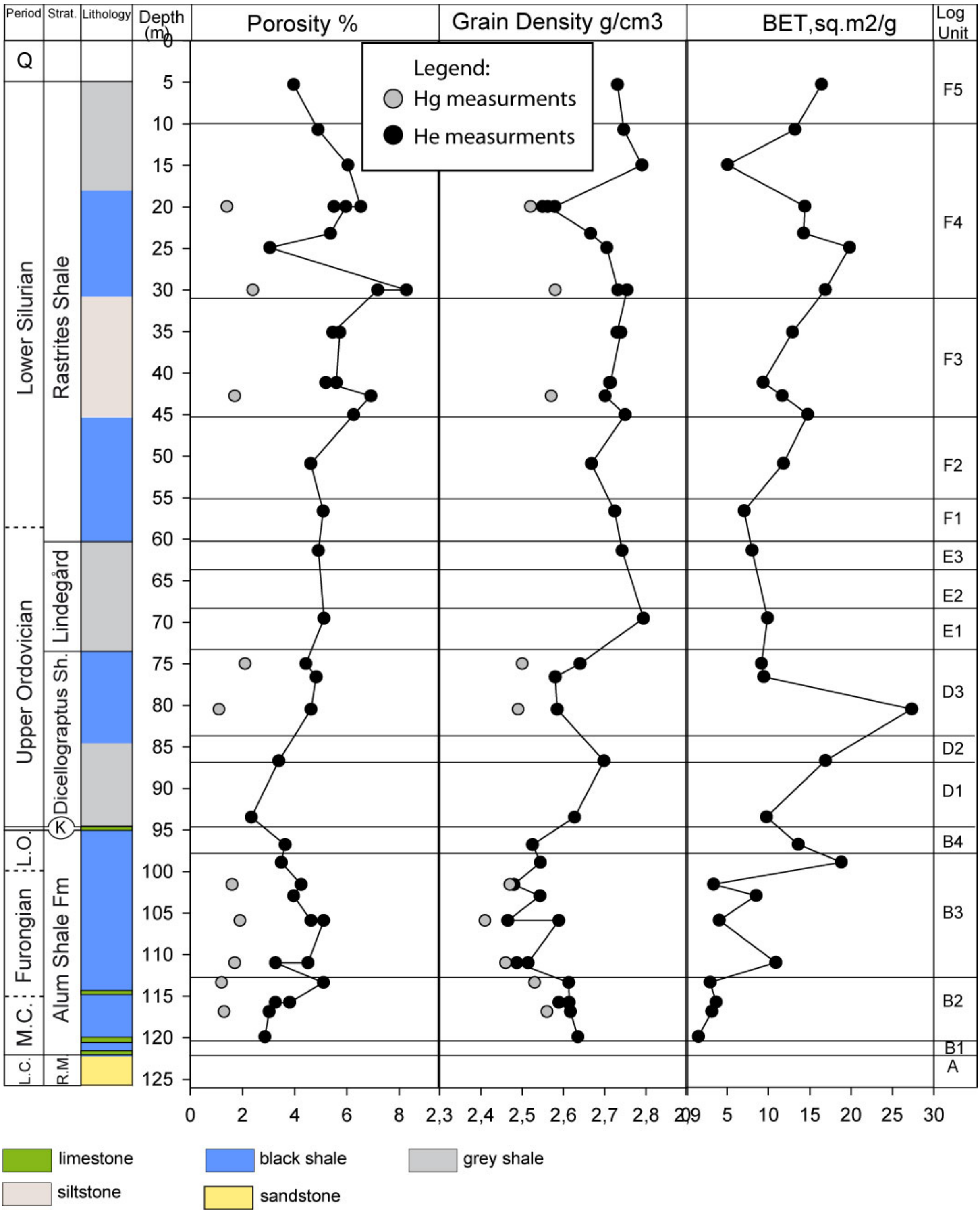


Figure 3. Variation in porosity, grain density and surface area (BET) in the Billegrav-2 well. Lithology and stratigraphy after Schovsbo et al. (2011).

Table 3. He-porosity, grain density, BET and Hg-injection data. Radius and PSD (normalised pore size distribution) at 50% Hg and 10% Hg denotes the pore throat radius in nm where 10% and 50% respectively of the sample pore volume have been filled by injected mercury. Subsamples are indicated with a .1 or .2.

Plug	Depth	Unit	Porosity (He)	Grain density	BET	Porosity (Hg)	Grain density	Hg entry pressure	Pores @ 50%Hg		Pores @ 10%Hg	
no.	base		%	g/cm3	m^2/g	%	g/cm3	bar	r50 (nm)	PSD 50	r10 (nm)	PSD 10
1	5.28	F5	4.0	2.73	16							
2	10.70	F5	4.9	2.75	13							
3	14.97	F4	6.0	2.79	5							
4	19.95	F4	6.5	2.58	14	1.4	2.52	4985	4	0.7	11	0.2
4.1	19.95	F4	5.5	2.55								
4.2	19.95	F4	6.0	2.56								
5	23.18	F4	5.4	2.67	14							
6	24.90	F4	3.1	2.71	20							
7	29.99	F4	8.3	2.73	17	2.4	2.58	3989	4	0.6	14	0.3
7.1	29.99	F4	7.2	2.75								
8	35.10	F3	5.5	2.73	13							
8.1	35.10	F3	5.7	2.74								
9	41.15	F3	5.6	2.71	9							
9.1	41.15	F3	5.2	2.71								
10	42.74	F3	6.9	2.70	12	1.7	2.57	4986	4	0.7	13	0.2
11	45.00	F3	6.3	2.75	15							
12	50.90	F1	4.6	2.67	12							
13	56.60	F1	5.1	2.72	7							
14	61.37	E3	4.9	2.74	8							
15	69.53	E1	5.1	2.79	10							
16	74.99	D3	4.4	2.64	9	2.1	2.50	3991	4	0.4	14	0.2
17	76.59	D3	4.8	2.58	9							
18	80.47	D3	4.6	2.59	27	1.1	2.49	2992	4	0.5	16	0.2
19	86.68	D2	3.4	2.70	17							
20	93.47	D1	2.3	2.63	10							
21	96.76	B4	3.6	2.53	14							
22	98.90	B3	3.5	2.54	19							
23	101.57	B3	4.3	2.48	3	1.6	2.47	4984	3	0.6	11	0.2
24	102.93	B3	4.0	2.54	9							
25	105.90	B3	4.6	2.47	4	1.9	2.41	5982	3	0.5	9	0.1
25.1	105.90	B3	5.1	2.59								
26	110.98	B3	4.5	2.51	11	1.7	2.46	3989	4	0.5	14	0.2
26.1	110.98	B3	3.3	2.49								
27	113.35	B2	5.1	2.61	3	1.2	2.53	3991	4	0.5	13	0.1
28	115.75	B2	3.8	2.61	4							
28.1	115.75	B2	3.3	2.59								
29	116.86	B2	3.0	2.62	3	1.3	2.56	2992	4	0.6	13	0.1
30	119.90	B2	2.9	2.64	2							

3.2. Hg-injection

Hg-injection measurements were made on 10 samples. The results are presented in Table 3 and are further detailed in Appendix A. All data collected during the experiments are presented in the file: 'Appendix A Hg injection data.xlsx' available on the attached CD.

Hg-injection method

The measurements were made at SKM Services in Aberdeen since GEUS no longer perform this analysis. The laboratory uses a Micromeritics Autopore-IV porosimeter. Hg capillary pressure was 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.:

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

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:

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

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

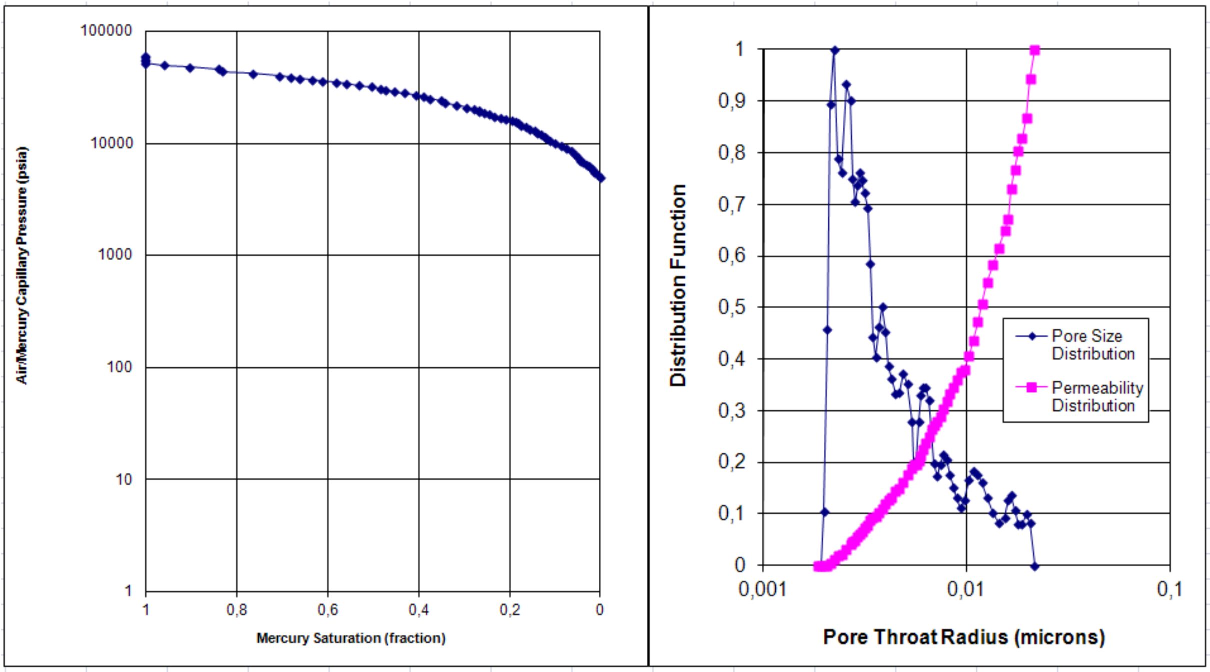


Figure 4. Example of the mercury injection diagrams showing characteristics for the pore system of the sample at 101.5m in the Alum Shale Formation. See appendix A for additional data on the Hg-injection.

<u>He-and Hg-porosities</u>

He-porosity measurements range between 2.8-5.1% in the Alum Shale. Porosities of 5.1% occur in the B2 and B3 units (Figure 3). In the Dicellograptus Shale the porosity ranges between 2.3-4.8% and in the Rastrites shale the porosity ranges between 3.1-8.3%. Determination of porosity on subsamples show a difference of up to 1.1% porosity units. This difference likely reflects that the sample material is not homogeneous on a small scale. Hence cm-scale variation of up to 20-30 relative % has to be anticipated.

Hg-injection porosities range up to 2.4% in the Billegrav-2 well (Figure 3 and Table 3). The Hg-injection porosity accounts for 21-47% of the porosity measured by the He-method. This indicates that a significant part of the pore system in the samples is below the resolution of the Hg-injection and thus within the micro-pore size range.

<u>Grain densities</u>

The grain density obtained from the He-porosity measurements varies between 2.45-2.8 g/cm^3 whereas the grain density obtained from the Hg-measurements varies between 2.4-2.6 g/cm^3. The slightly lower grain density obtained by the Hg-method is probably due to lower porosities measured by the Hg-method compared to the He-methods (Figure 5) since this affects the calculated grain densities.

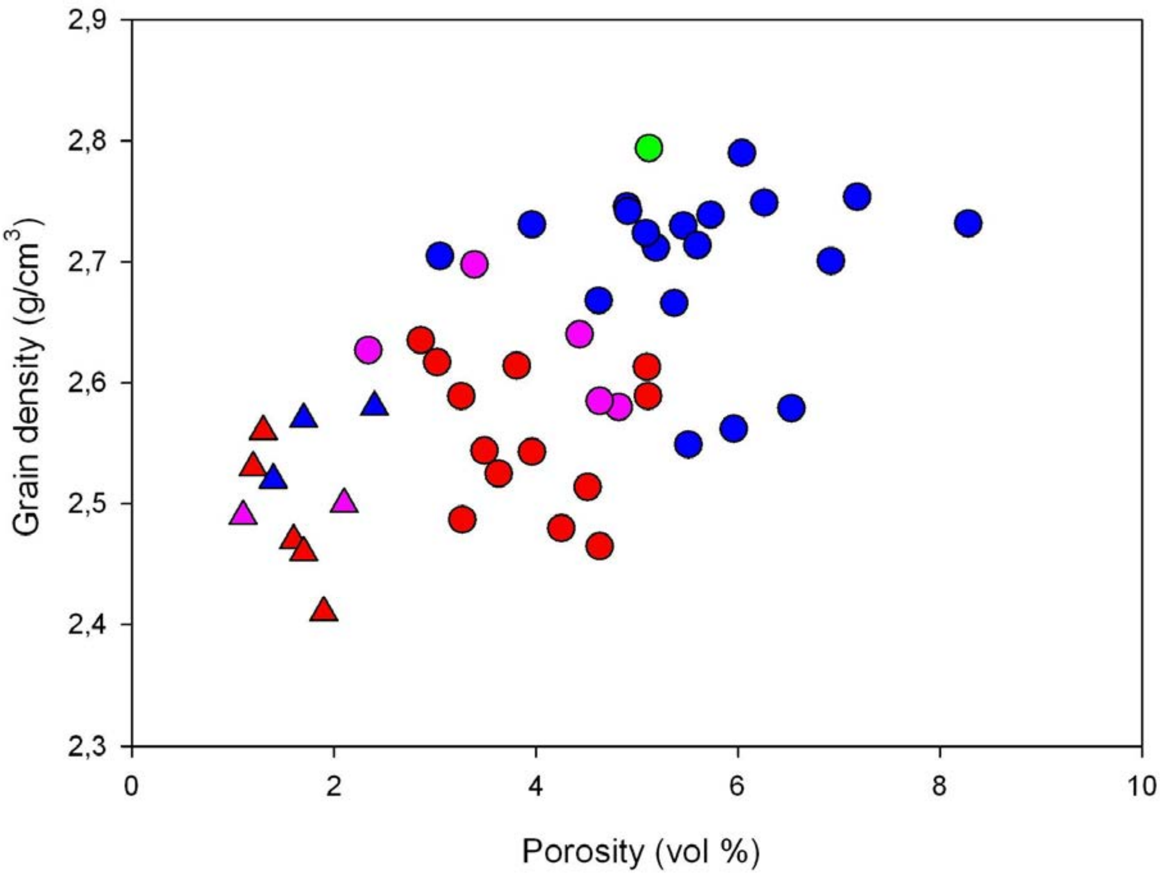


Figure 5. Relationship between porosity and grain density. Circles: He-measurements; triangles: Hg-measurements. Fill colour: red: Alum Shale; pink: Dicellograptus Shale; green: Lindegård Fm.; blue: Rastrites Shale.

Hg-entry pressure and pore radius distribution

The Alum Shale samples have a sharp high entry pressure that range between 3000-6000 psia in the air/mercury capillary pressure plot (Figure 4 and Appendix A). The pore throat size distribution is typical bi-modal; a stable plateau is not reached until filling of ~ 20% of the pore volume representing the largest pore throat radii (Figure 4). The Dicellograptus Shale and the Rastrites shale have Hg entry pressures and pore size distributions that are similar to those seen in the Alum Shale (Table 3 and Appendix A).

3.3. BET measurements

<u>Specific surface area method</u>

Before measuring the N2-BET specific surface area, the samples were out-gassed at high vacuum at 20°C. Subsequently, the specific surface was determined by nitrogen adsorption at liquid nitrogen temperature in a Micromeritics Accusorb instrument by application of the BET equation. The data is presented in Table 3.

The surface area varies between 2-19 m^2/g in the Alum Shale, between 9-27 m^2/g in the Dicellograptus shale and between 5-20 m^2/g in the Rastrites shale (Figure 3, Table 3). Highest surface area is measured in the uppermost parts of the Furongian Alum Shale (B3 unit). In the Dicellograptus and Rastrites shales highest surface area occurs in the D3 and F4 units. The B3, D3 and F4 units are all the most TOC rich units in the shales. This suggest that there is some control between surface area and TOC enrichment although the surface area is not itself correlated with the TOC content (Figure 6A).

No correlation between He-porosities and surface area can be seen (Figure 6B).

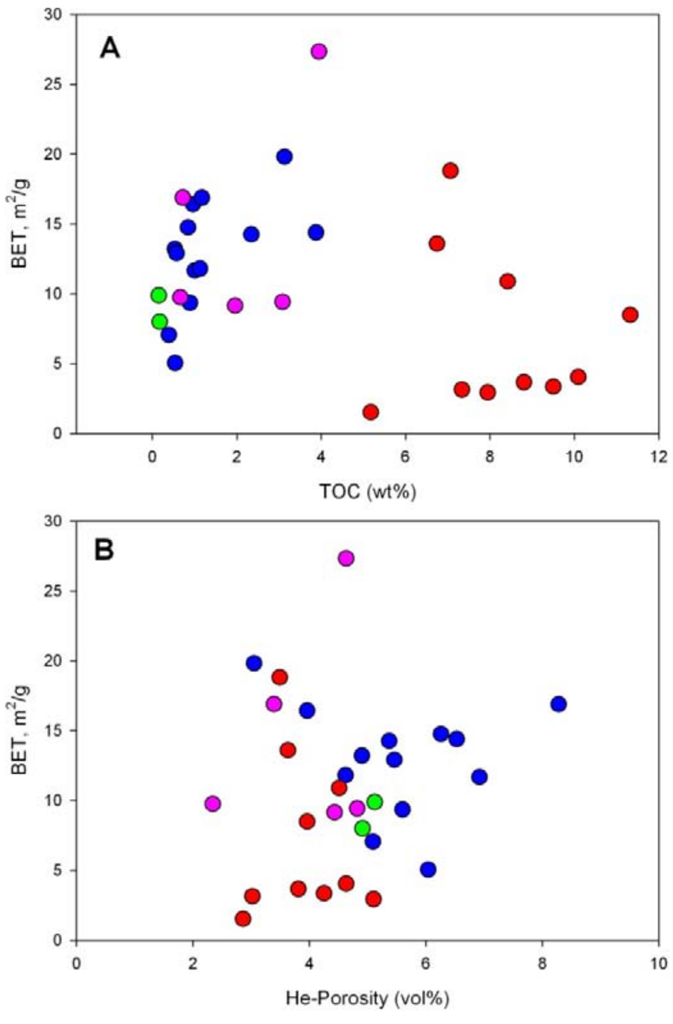


Figure 6. Surface area (BET) versus A) TOC content and B) He-porosity. Fill colour: red, Alum Shale; pink, Dicellograptus Shale; green, Lindegård; blue, Rastrites Shale.

3.4. Grain density and porosity

Grain Density

The grain density of sample with low content of TOC, pyrite and carbonate appear to be approximately 2.75 g/cm3 (Figure 7A). This value appears to represent the average density of the ‘clay matrix’.

TOC and quartz have lower grain densities than the ‘clay matrix’, whereas the carbonate component appears to have similar grain density than the ‘clay matrix’ (Figure 7). Pyrite appears also to have a lower density than the clay-matrix since the grain density decreases with increasing pyrite content (Figure 7B). Pyrite/marcasite is, however, expected to have grain densities between 3-5 g/cm^3 and the apparent decrease in grain density with increasing pyrite content reflect the association of TOC with pyrite (Figure 7B). In the Alum Shale the grain density thus appear controlled by the presence of organic carbon with variable pyrite content hence two modes of organic carbon can be outlined: a ‘heavy TOC mode’ and a ‘light TOC mode’. The ‘heavy TOC mode’ is characterised by relative high sulphur content whereas the ‘light TOC mode’ is characterised by relatively low sulphur content relative to TOC (Figure 7C).

The Dicellograptus Shale appears to be a relative quartz rich shale compared to the other units (Figure 7D). The grain densities in the Dicellograptus Shale decreases with increasing TOC content. The TOC has relative low pyrite content and is thus relatively ‘light’. The Rastrites Shale has variable carbonate content and are generally also quartz rich. The sulphur content is relatively high compared to the TOC level.

Porosity

Both positive and negative controls on the porosity have been identified (Figure 8). The strongest positive control appears to be to the organic carbon content suggesting that the majority of the porosity is associated with this component (Figure 8C). The relationship between TOC and porosity are, however, different between the formations and no general relationship can be expressed (Figure 8C).

The Alum Shale appears to contain the least porous organic carbon, the Dicellograptus Shale and the F4 unit appears to contain organic carbon with intermediate porosities and the remaining Rastrites samples appears to contain the most porous organic carbon (Figure 8C).

There is also an overall positive effect on the porosity from the quartz content whereas there is an overall negative effect on the porosity from the carbonate and pyrite content (Figure 8A and B). These relationships may also in part explain the porosity- TOC relationship in Figure 8C).

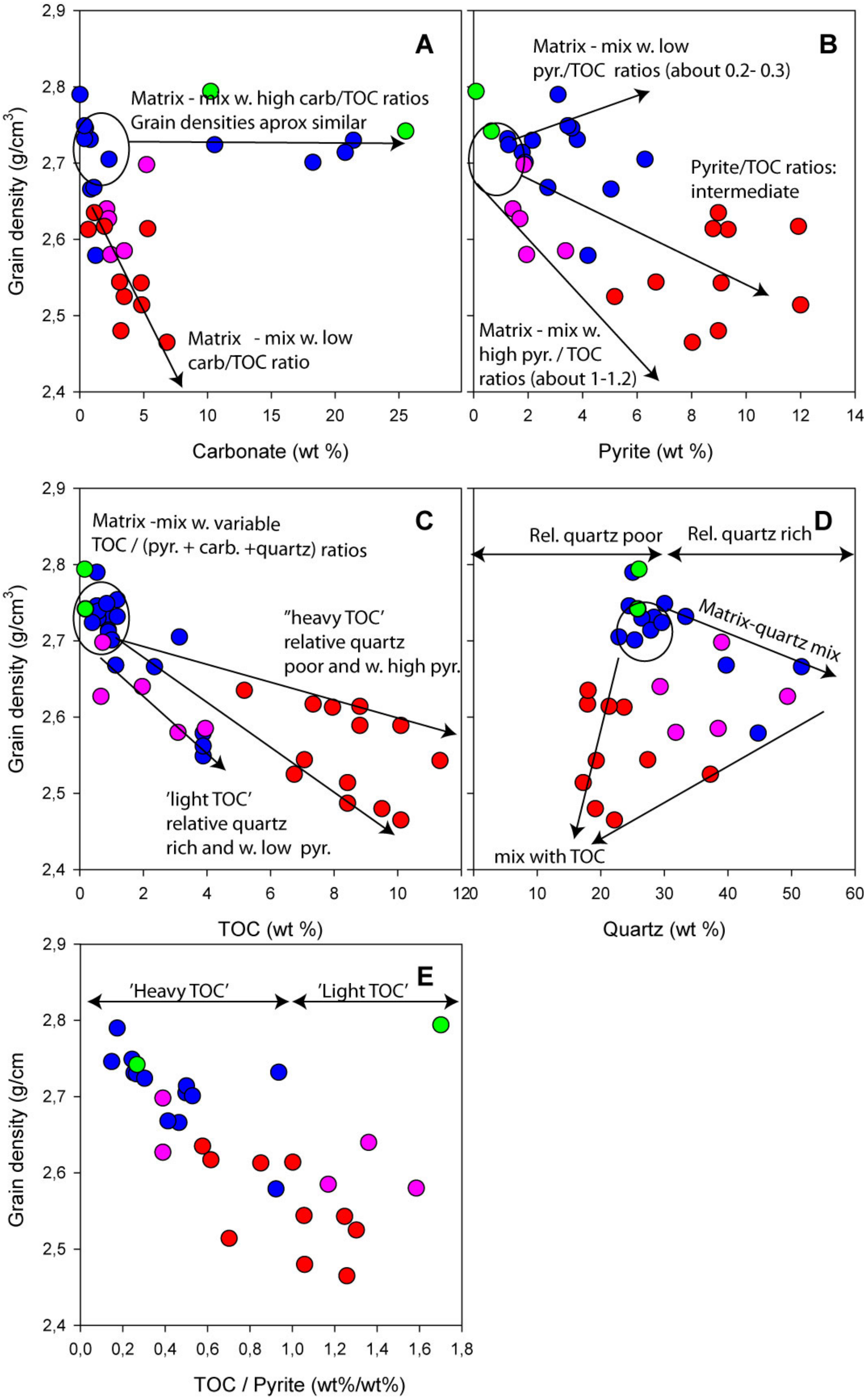


Figure 7. Grain density (He-porosity measurements) versus (A) carbonate content, (B) pyrite content, (C) TOC content, (D) quartz content and (E) TOC / pyrite ratio. Fill colour: red, Alum Shale; pink, Dicellograptus Shale; green, Lindegård; blue, Rastrites Shale. The mineralogical composition is presented in Tables 6a and 6b. Arrows indicate general trends in the data.

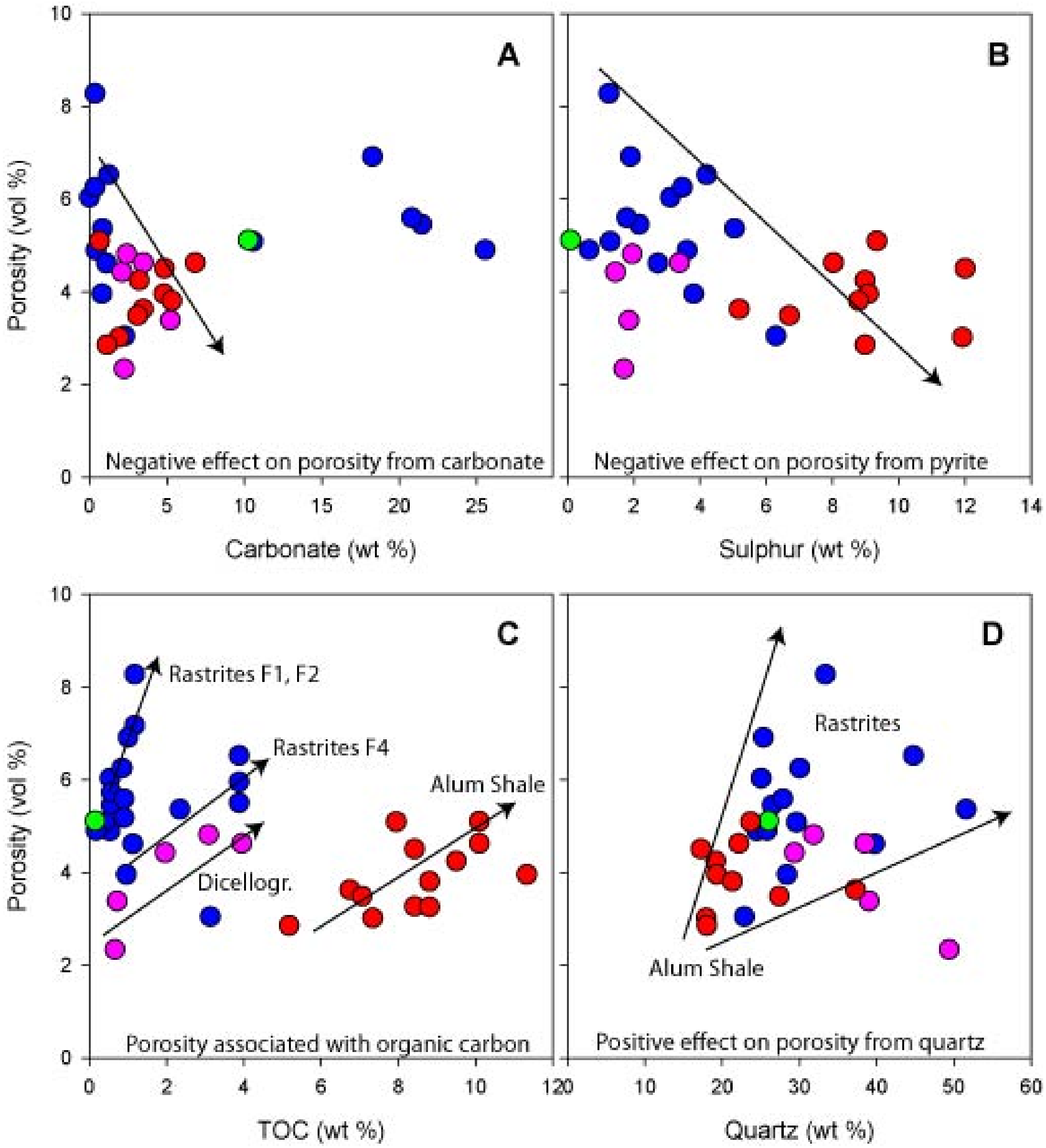


Figure 8. He-porosity measurements versus (A) carbonate content, (B) pyrite content, (C) TOC content and (D) quartz content. Fill colour: red, Alum Shale; pink, Dicellograptus Shale; green, Lindegård; blue, Rastrites Shale. The mineralogical composition is detailed in Table 6. Arrows indicate general trends in the data that should be validated by detailed petrophysical modelling.

4. TOC and Rock Eval measurements

Rock Eval measurements were analyzed using a Delsi Rock Eval instrument. Results include S1 and S2 pyrolysis yields and temperature of maximal S2 yield (Tmax). Hydrogen index (HI) is calculated as the S2 pyrolysis yield normalized to the TOC content. Total organic carbon (TOC) was measured by combustion of acid treated carbonate-free samples in a LECO-type oven. Measurements of total carbon (TC) and total sulphur (TS) were made on untreated samples combusted also in a LECO-type oven. All measurements were made at GEUS Source Rock Laboratory. The data is presented in Table 4.

Tmax and hydrogen index

The Tmax range between 483-608^{o}C, S1 yields are zero, S2 yields range between 0-0.2 mg HC/g rock and HI value ranges between 0-2 mg HC/g TOC (Table 4). The high Tmax and low HI values indicate a high maturity of the samples. This is in agreement with 'vitrinite-like' reflectance values of 2.5% Ro measured on samples from the Billegrav-1 well (Buchardt et al. 1986, Schovsbo 2011c).

TOC and S content

The TOC content in the Billegrav-2 range between 0.5-11.3% (Table 4). In the Alum Shale the TOC content range between 5.2-11.3%. Highest values are observed in the B3 unit. In the Dicellograptus Shale the TOC content range between 0.7-4.0% with highest TOC concentrations in the D3 unit. In the Rastrites Shale the TOC content range between 0.6-3.9% with highest TOC content in the F4 unit (Figure 10).

The S content increases with increasing TOC content (Figure 9). The Alum Shale is characterised by rather variable TOC/S ratios. The Dicellograptus shale is characterised by low S compared to the TOC content whereas the Rastrites Shale is characterised by relatively high S content compared to the TOC content (Figure 9).

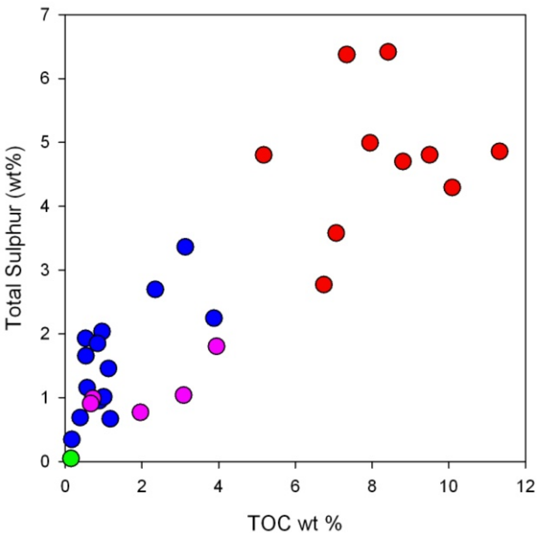


Figure 9. Relationship between TOC and sulphur content. Legend: red: Alum Shale, Pink: Dicellograptus Shale, green: Lindegård Fm., blue: Rastrites Shale.

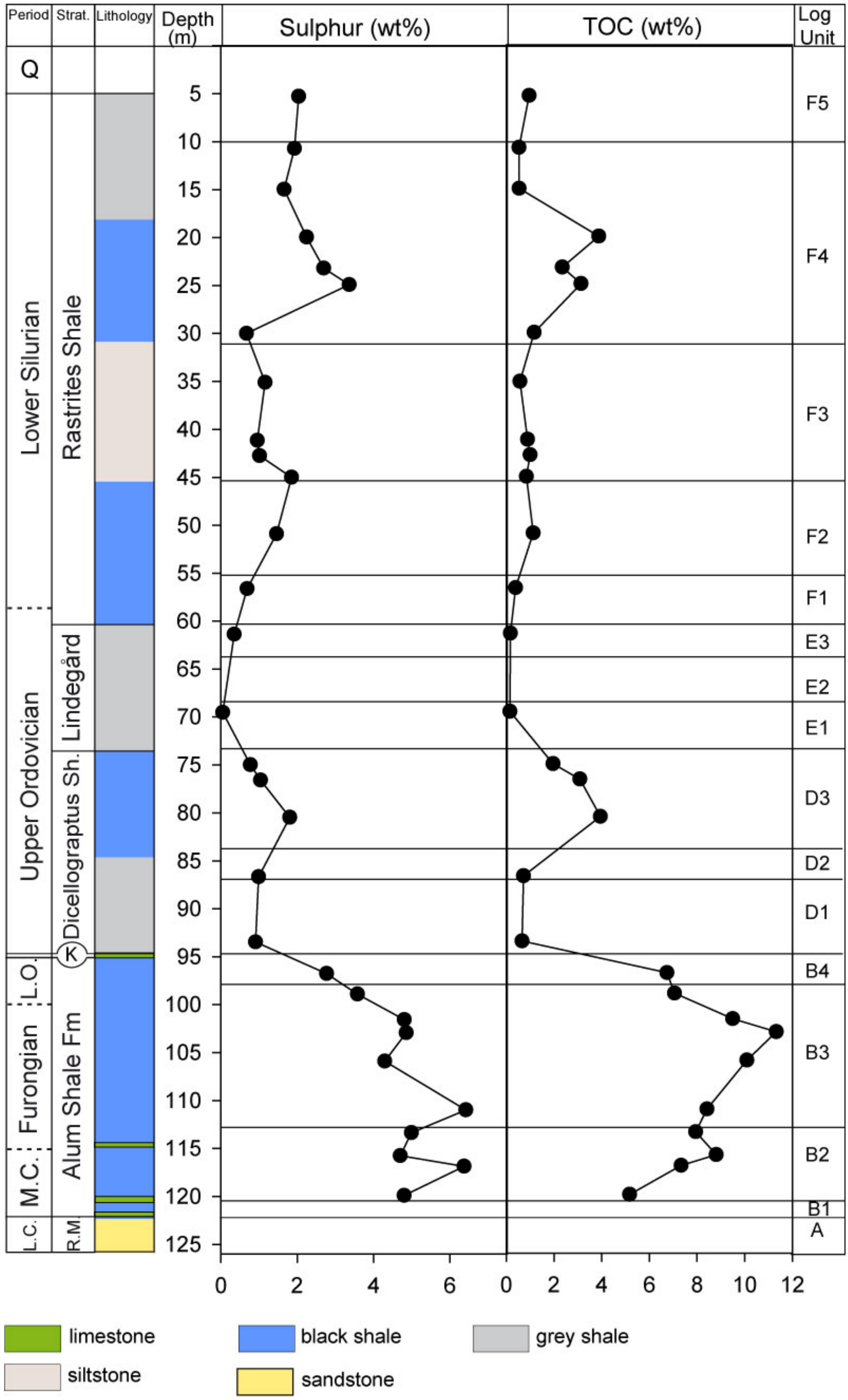


Figure 10. Variation of TOC and sulphur content in the Billegrav-2 well. Lithology and stratigraphy is after (Schovsbo et al. 2011).

Table 4. Rock Eval and TOC results from the Billegrav-2 well. Tmax temperatures in () indicate unreliable low temperatures. These samples all are low in TOC cotent.

sample	Formation	Unit	Depth	TOC	Tmax	S1	S2	HI	TC	TS	Carb.
			m	wt%	°C	mg/g	mg/g	mg/g TOC	wt%	wt%	wt%
1	Rastrites	F5	5.28	1.0	(498)	0	0.0	0	1.1	2.0	0.8
2	Rastrites	F4	10.70	0.5	(490)	0	0.0	0	0.6	1.9	0.4
3	Rastrites	F4	14.97	0.5	(486)	0	0.0	0	0.5	1.7	0.0
4	Rastrites	F4	19.95	3.9	608	0	0.0	0	4.0	2.2	1.2
5	Rastrites	F4	23.18	2.3	(491)	0	0.0	0	2.4	2.7	0.8
6	Rastrites	F4	24.90	3.1	608	0	0.0	0	3.4	3.4	2.3
7	Rastrites	F4	29.99	1.2	608	0	0.0	0	1.2	0.7	0.4
8	Rastrites	F3	35.10	0.6	n.d.	0	0.0	0	3.1	1.2	21.4
9	Rastrites	F3	41.15	0.9	(481)	0	0.0	0	3.4	1.0	20.8
10	Rastrites	F3	42.74	1.0	(496)	0	0.0	0	3.2	1.0	18.3
11	Rastrites	F3	45.00	0.8	(494)	0	0.0	0	0.9	1.9	0.4
12	Rastrites	F2	50.90	1.1	(485)	0	0.0	0	1.3	1.5	1.1
13	Rastrites	F1	56.60	0.4	n.d.	0	0.0	0	1.7	0.7	10.6
14	Lindegård	E3	61.37	0.2	n.d.	0	0.0	0	3.2	0.3	25.5
15	Lindegård	E1	69.53	0.2	501	0	0.0	0	1.4	0.0	10.2
16	Dicellogp.	D3	74.99	2.0	607	0	0.0	0	2.2	0.8	2.1
17	Dicellogp.	D3	76.89	3.1	606	0	0.0	1	3.4	1.0	2.4
18	Dicellogp.	D3	80.47	3.9	607	0	0.0	1	4.4	1.8	3.5
19	Dicellogp.	D2	86.68	0.7	(443)	0	0.0	0	1.3	1.0	5.2
20	Dicellogp.	D1	93.47	0.7	(483)	0	0.0	0	0.9	0.9	2.2
21	Alum	B4	96.76	6.7	607	0	0.1	2	7.2	2.8	3.5
22	Alum	B3	98.90	7.1	607	0	0.1	2	7.4	3.6	3.1
23	Alum	B3	101.57	9.5	607	0	0.2	2	9.9	4.8	3.2
24	Alum	B3	102.93	11.3	608	0	0.2	2	11.9	4.9	4.8
25	Alum	B3	105.90	10.1	607	0	0.2	1	10.9	4.3	6.8
26	Alum	B3	110.98	8.4	607	0	0.1	1	9.0	6.4	4.8
27	Alum	B2	113.35	7.9	607	0	0.0	0	8.0	5.0	0.6
28	Alum	B2	115.75	8.8	608	0	0.1	1	9.4	4.7	5.3
29	Alum	B2	116.86	7.3	(469)	0	0.0	0	7.6	6.4	1.9
30	Alum	B2	119.90	5.2	606	0	0.0	0	5.3	4.8	1.1

5. Mineralogical measurements

The XRD powder diffraction patterns were obtained on randomly oriented powder (ground to less than 250 microns) using CoKα-radiation. Merck quartz 1.07536 ground down to <0.063 micron was used as standard. The analysis was made at the GEUS clay laboratory.

The XRD spectra were investigated for the main mineral groups. Identified mineral groups include kaolinite, mica, clay, quartz, calcite, dolomite/ankerite and pyrite/marcasite. Barite and feldspar was not identified.

The results of the mineralogical screening of the samples are presented in Table 5. In the table the reflection areas of the minerals are presented. The XRD spectra are included on the attached CD in the Appendix folder.

5.1. Quantitative

In order to quantify the main mineralogical composition in the samples the following components have been calculated (Table 6a):

Carbonate content: Measured directly on the sample by titration technique.

Pyrite (FeS_2) content: Calculated from total sulphur (TS) content assuming that all sulphur is present in pyrite.

Organic matter content: Calculated directly from the TOC content.

Quartz content: Measured by X-ray diffraction by comparing peak heights between the sample and a standard.

% unresolved: Proportion of the sample that is not accounted for by the analysis of the above mentioned phases. Calculated from the formula: 100% – (%Quartz + %TOC + %Pyrite + %Carbonate).

The Q/(Q+ clay) ratio: Calculated from the quantitative measurement of quartz (Table 6a) and the semi quantitative concentration of total clay (Table 6b).

5.2. Semi-quantitative

The content of the mineral phases identified from during the bulk XRD screening of the samples are measured in area of reflectivity (comparable to peak height) (Table 5). For pyrite and carbonate the reflectivity scale is directly proportional with the measured concentrations (Figure 11).

The reflectivity for kaolinite, mica, clay and plagioclase has been scaled to the proportion of the sample that is not accounted for by the quantitative mineralogical analysis. In this manner a semi-quantitative measurement of these phases have been established (Table 6b).

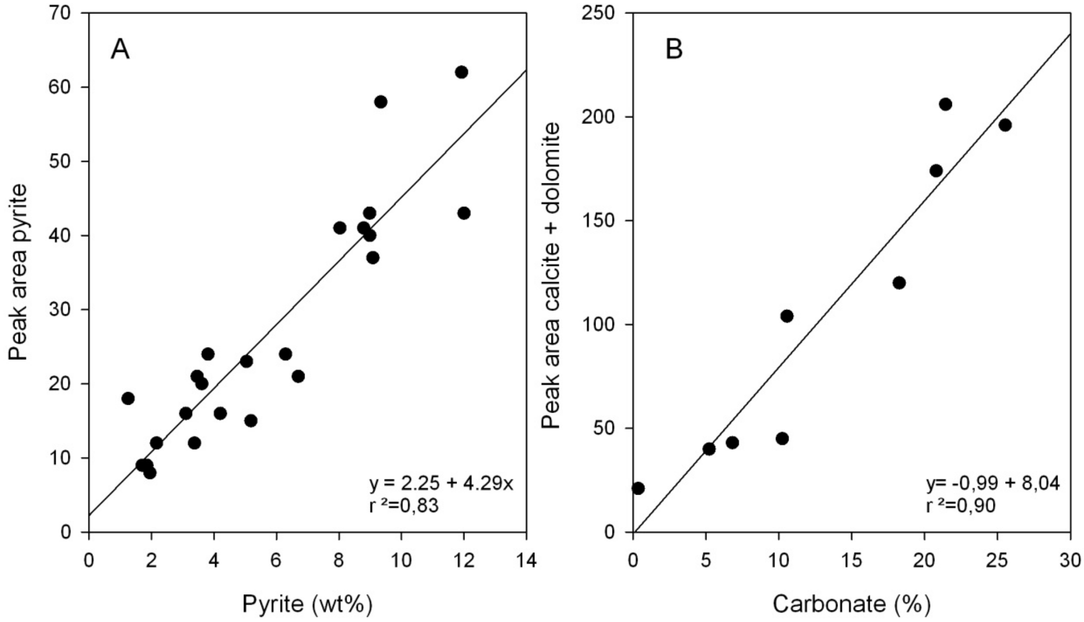


Figure 11. Comparison between area of reflectivity for (A) pyrite/marcasite and (B) carbonate (calcite, dolomite and ankerite) with the measured quantity.

Quartz content

The quartz content in the Alum Shale range between 18-37% (Figure 12). Highest content are measured in the Ordovician part of the formation. A local high is observed in the basal part of the Furongian (topmost B2 unit in Figure 12). The quartz content in the Dicellograptus Shale range between 29-49%. Highest concentrations are measured in the basal part of the formation in shales interbedded with bentonite. The quartz content in the Rastrites shale range between 24-52%. Highest concentrations are measured in the F4 unit.

Carbonate content

The carbonate content in the Alum Shale range between 0.6-6.8% (Figure 12). Highest content are measured in the B3 unit. The Dicellograptus Shale has low carbonate content that range between 2.1-5.2%. The carbonate content in the Lindegård Fm range between 10.2-25.5%. The highest value is measured in a sample from the E3 unit. The carbonate content in the Rastrites shale range between 0-21.4%. Concentrations above 15% are measured in the F3 unit (Figure 12). This unit contains abundant carbonate cemented beds (Schovsbo et al. 2011).

Table 5. Identified minerals on the XRD spectra. Numbers refers to area of reflectivity (peak height) measured on the XRD spectra. Spectra are included on the attached CD.

Formation	Unit	Depth base	Kaolinite	Mica	Clay	Quartz	Plagio.	Calcite	Pyrite/ Marcasite	Ankerite/ dolomite
		m	7 Å	5 Å	4.48 Å	4.26 Å	4.03 Å	3.03	1.63 Å	2.89 Å
Rastrites	F5	5.28	30	13	23	94			24	
Rastrites	F4	10.70	39	16	26	95			20	
Rastrites	F4	14.97	37	10	32	85			16	
Rastrites	F4	19.95	14	8	26	118			16	
Rastrites	F4	23.18	19	9	29	103			23	
Rastrites	F4	24.90	20	12	30	62			24	
Rastrites	F4	29.99	32	12	35	126			18	
Rastrites	F3	35.10	23	12	21	101		206	12	
Rastrites	F3	41.15	22	16	20	110		174		
Rastrites	F3	42.74	27	11	22	87		120		
Rastrites	F3	45.00	36	13	36	91			21	
Rastrites	F2	50.90	38	15	29	161				
Rastrites	F1	56.60	43	14	25	110		104		
Lindegård	E3	61.37	28	11	23	94		196		
Lindegård	E1	69.53	67	9	31	75				45
Dicellogp.	D3	74.99	23	13	27	114				
Dicellogp.	D3	76.89	16	8	19	101			8	
Dicellogp.	D3	80.47	13	7	15	124			12	
Dicellogp.	D2	86.68	23	11	21	129		40	9	
Dicellogp.	D1	93.47			18	156			9	
Alum	B4	96.76	11	12	24	143			15	
Alum	B3	98.90	8	14	25	117			21	
Alum	B3	101.57		15	23	88			40	
Alum	B3	102.93		14	25	73			37	
Alum	B3	105.90		17	26	84		43	41	
Alum	B3	110.98		14	20	79			43	
Alum	B2	113.35		15	25	90			58	
Alum	B2	115.75		14	28	73			41	
Alum	B2	116.86	12	14	20	71			62	
Alum	B2	119.90	16	19	24	82			43	

Table 6a. Quantitative mineralogical composition.

Sample	Formation	Unit	Depth base	Quantitative				
			m	TOC %	Carb. %	Pyrite %	Q %	Unresolved %
1	Rastrites	F5	5.28	1.0	0.8	3.8	28	66
2	Rastrites	F4	10.70	0.5	0.4	3.6	24	71
3	Rastrites	F4	14.97	0.5	0.0	3.1	25	71
4	Rastrites	F4	19.95	3.9	1.2	4.2	45	46
5	Rastrites	F4	23.18	2.3	0.8	5.0	52	40
6	Rastrites	F4	24.90	3.1	2.3	6.3	23	65
7	Rastrites	F4	29.99	1.2	0.4	1.3	33	64
8	Rastrites	F3	35.10	0.6	21.4	2.2	26	49
9	Rastrites	F3	41.15	0.9	20.8	1.8	28	49
10	Rastrites	F3	42.74	1.0	18.3	1.9	25	53
11	Rastrites	F3	45.00	0.8	0.4	3.5	30	65
12	Rastrites	F2	50.90	1.1	1.1	2.7	40	55
13	Rastrites	F1	56.60	0.4	10.6	1.3	30	58
14	Lindegård	E3	61.37	0.2	25.5	0.6	26	48
15	Lindegård	E1	69.53	0.2	10.2	0.1	26	64
16	Dicellogp.	D3	74.99	2.0	2.1	1.4	29	65
17	Dicellogp.	D3	76.89	3.1	2.4	1.9	32	61
18	Dicellogp.	D3	80.47	3.9	3.5	3.4	38	51
19	Dicellogp.	D2	86.68	0.7	5.2	1.9	39	53
20	Dicellogp.	D1	93.47	0.7	2.2	1.7	49	46
21	Alum	B4	96.76	6.7	3.5	5.2	37	47
22	Alum	B3	98.90	7.1	3.1	6.7	27	56
23	Alum	B3	101.57	9.5	3.2	9.0	19	59
24	Alum	B3	102.93	11.3	4.8	9.1	19	55
25	Alum	B3	105.90	10.1	6.8	8.0	22	53
26	Alum	B3	110.98	8.4	4.8	12.0	17	57
27	Alum	B2	113.35	7.9	0.6	9.3	24	58
28	Alum	B2	115.75	8.8	5.3	8.8	21	56
29	Alum	B2	116.86	7.3	1.9	11.9	18	61
30	Alum	B2	119.90	5.2	1.1	9.0	18	67

Table 6b (continued). Semi-quantitative mineralogical composition.

				Semi-quantitative				
Sample	Formation	Unit	depth (m)	% Kaolinite	% Mica	% Clay	% Plagio.	Q/(Q+Clay)
1	Rastrites	F5	5.28	30	13	23	0	0.55
2	Rastrites	F4	10.70	34	14	23	0	0.52
3	Rastrites	F4	14.97	33	9	29	0	0.46
4	Rastrites	F4	19.95	13	8	25	0	0.64
5	Rastrites	F4	23.18	13	6	20	0	0.72
6	Rastrites	F4	24.90	21	13	32	0	0.42
7	Rastrites	F4	29.99	26	10	28	0	0.54
8	Rastrites	F3	35.10	20	11	19	0	0.59
9	Rastrites	F3	41.15	18	13	17	0	0.62
10	Rastrites	F3	42.74	24	10	20	0	0.56
11	Rastrites	F3	45.00	28	10	28	0	0.52
12	Rastrites	F2	50.90	26	10	20	0	0.67
13	Rastrites	F1	56.60	31	10	18	0	0.63
14	Lindegård	E3	61.37	22	8	18	0	0.59
15	Lindegård	E1	69.53	40	5	18	0	0.59
16	Dicellogp.	D3	74.99	24	13	28	0	0.51
17	Dicellogp.	D3	76.89	23	11	27	0	0.54
18	Dicellogp.	D3	80.47	19	10	22	0	0.64
19	Dicellogp.	D2	86.68	22	11	20	0	0.66
20	Dicellogp.	D1	93.47	0	0	46	0	0.52
21	Alum	B4	96.76	11	12	24	0	0.61
22	Alum	B3	98.90	9	17	30	0	0.48
23	Alum	B3	101.57	0	23	36	0	0.35
24	Alum	B3	102.93	0	20	36	0	0.35
25	Alum	B3	105.90	0	21	32	0	0.41
26	Alum	B3	110.98	0	24	34	0	0.34
27	Alum	B2	113.35	0	22	37	0	0.39
28	Alum	B2	115.75	0	19	37	0	0.36
29	Alum	B2	116.86	16	19	26	0	0.40
30	Alum	B2	119.90	18	21	27	0	0.40

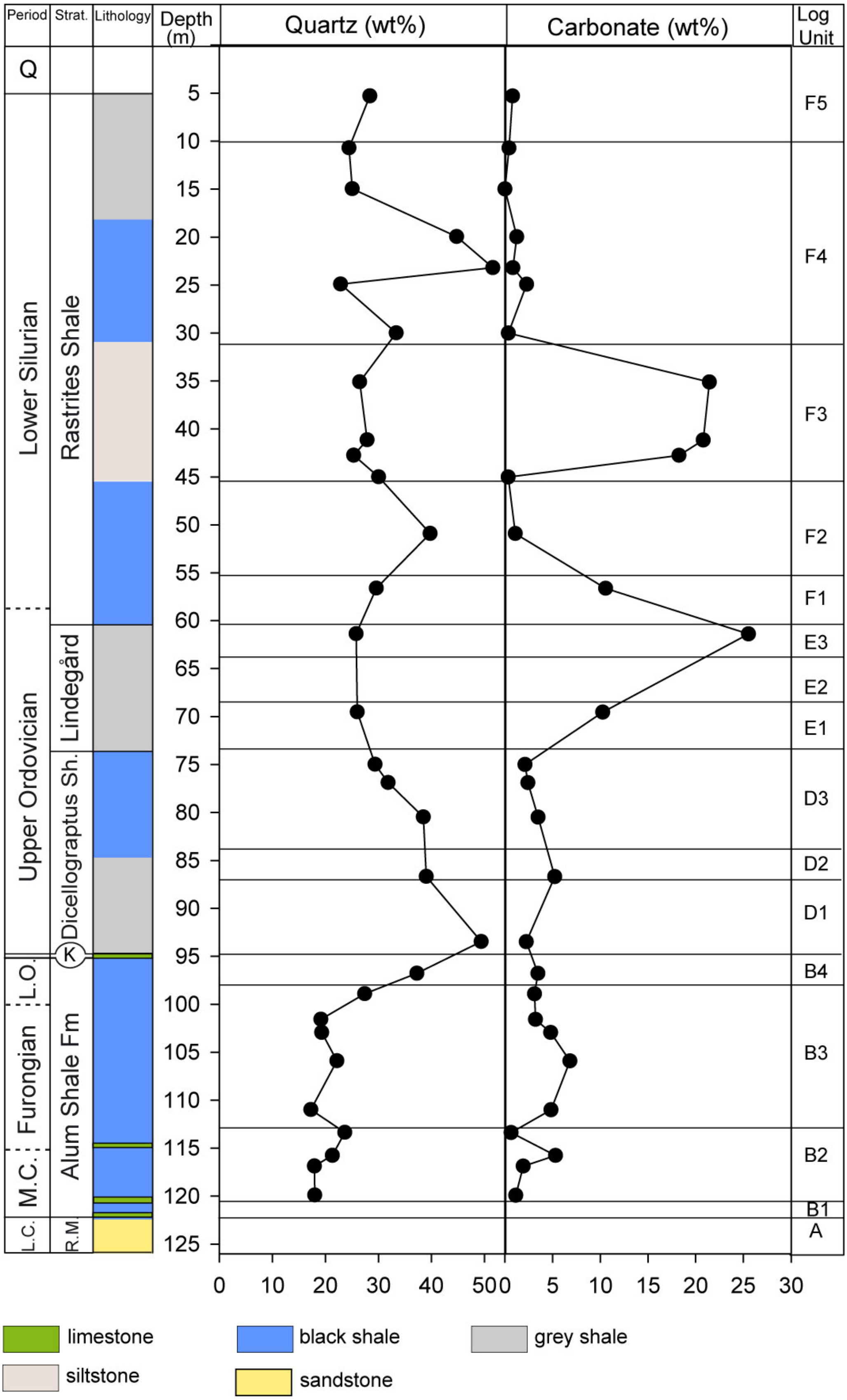


Figure 12. Variation of quartz and carbonate content in the Billegrav-2 well. Lithology and stratigraphy after Schovsbo et al. (2011).

6. Trace element measurements

Trace element concentrations were measured by GEUS on an PerkinElmer Elan 6100DRC ICP-MS apparatus. Calibration was done using synthetic (BHVO-2, GH, BIR-1) and natural (Disko-1) standards. The analytical results of the standards analysed together with the samples are presented in Appendix B together with the full analytical results. The results for selected trace elements are presented in Table 7.

The mass-spectra were evaluated using two methods: REE and TotalQuant. The main difference between the methods is that the 'REE' method is aimed at determining the concentrations of the rare earth elements (REE) since these elements requires calibration based on multiple standards whereas the TotalQuant methods requires fewer standards to be analysed.

The REE method provides the concentrations of the following 36 elements:

> Sc, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, U.

This method provides high quality quantitative results calibrated to reference samples. Elements determined by this methods is preferred.

The TotalQuant method provides the concentrations of the following 56 elements:

> Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hf, Ho, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pr, Rb, Sb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, Y, Yb, Zn, Zr.

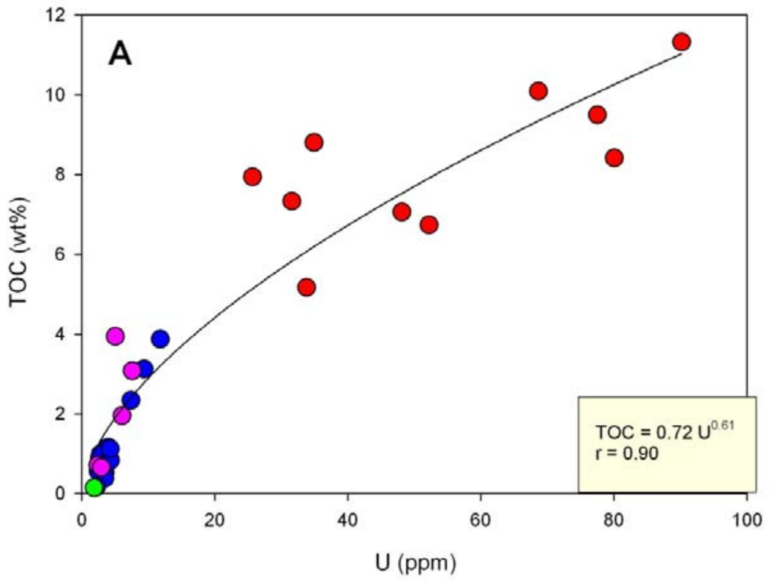
The TotalQuant method is developed by PerkinElmer's and provide less quantified element concentrations aimed at 'fingerprinting' of a sample with as many elements as possible.

6.1. U and V variation

The Alum Shale is well known for its high concentration of V and U that has a very distinct stratigraphical enrichment pattern (Andersson et al. 1985).

The V content in the Alum Shale range between 300-2086 ppm with highest concentrations in the topmost Furongian B3 unit at 101.57 m (Figure 14). The V concentrations in the Ordovician part of the formation are rather low compared to the Gislövshammar-2 drill-cores in Scania (Schovsbo 2001). V concentrations above 2000 ppm occur only occasionally in the Furongian and in the lowermost part of the Ordovician whereas concentrations consistently above 2000 ppm and typically around 4000 ppm occur in the middle part of the Ordovician Alum Shale (the 'As 3 zone') in Scania (Schovsbo 2001). The variation in V concentrations in Billegrav-2 indicates that the 'As-3 zone' was not sampled. This interval is likely to be present on Bornholm but is expected to be relative thin compared with Scania.

The V concentrations in the Alum Shale are related to the TOC content (Figure 13). At V concentrations less than 1000 ppm there is a good linear relationship between V concentration and TOC level. However, at V concentrations >1000 ppm the enrichment is not related to the TOC content making predictions of the TOC level from the V content impossible at high V concentrations. The V content in the Dicellograptus, Lindegård and Rastrites shales varies between 38-307 ppm with highest V content in TOC rich samples (Figure 13).



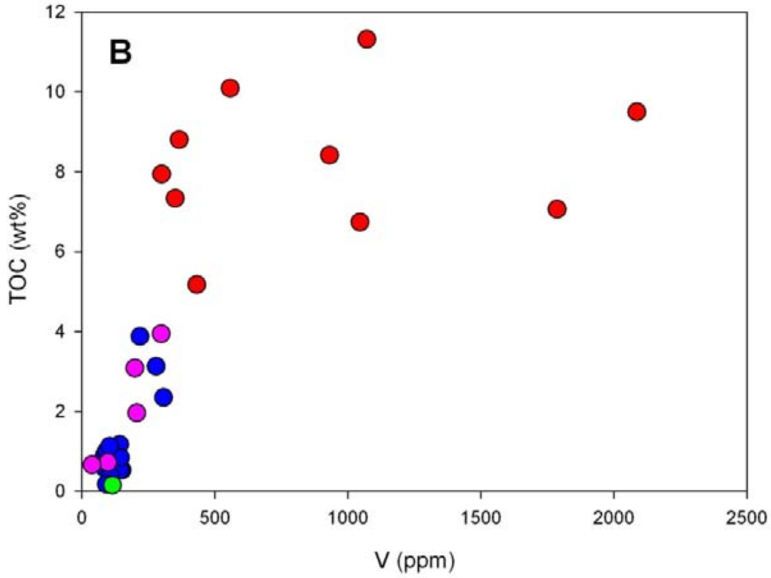


Figure 13. Relationship between TOC and (A) U and (B) V concentrations. Legend: Red: Alum Shale. Pink: Dicellograptus Shale. Green: Lindegård Fm., Blue: Rastrites Shale.

The U content in the Alum Shale range between 26-90 ppm (Figures 13, 4). Highest content is measured in the B3 unit. This unit was also defined as the log-unit with highest response on the gamma ray log curve (Pedersen, 1989; Pedersen & Klitten 1990). The U concentrations in the B3 unit are somewhat low compared to the concentrations measured in the Alum Shale in Sweden (Schovsbo 2002). It was anticipated that U concentrations approaching 200 ppm would have been measured in parts of the B3 unit in Billegrav-2. These U-rich horizons were apparently not sampled in the Billegrav-2 well.

The U content is related to the TOC content and a power function describing the relationship between U and TOC has been modelled (Figure 13). The relationship suggests that the TOC level can be predicted from the gamma log or from the spectral U log that has been obtained on the core (Schovsbo 2011a). The U content in the Dicellograptus, Lindegård and Rastrites Shales range between 3-12 ppm. The concentrations are strongly correlated to the TOC content (Figure 13).

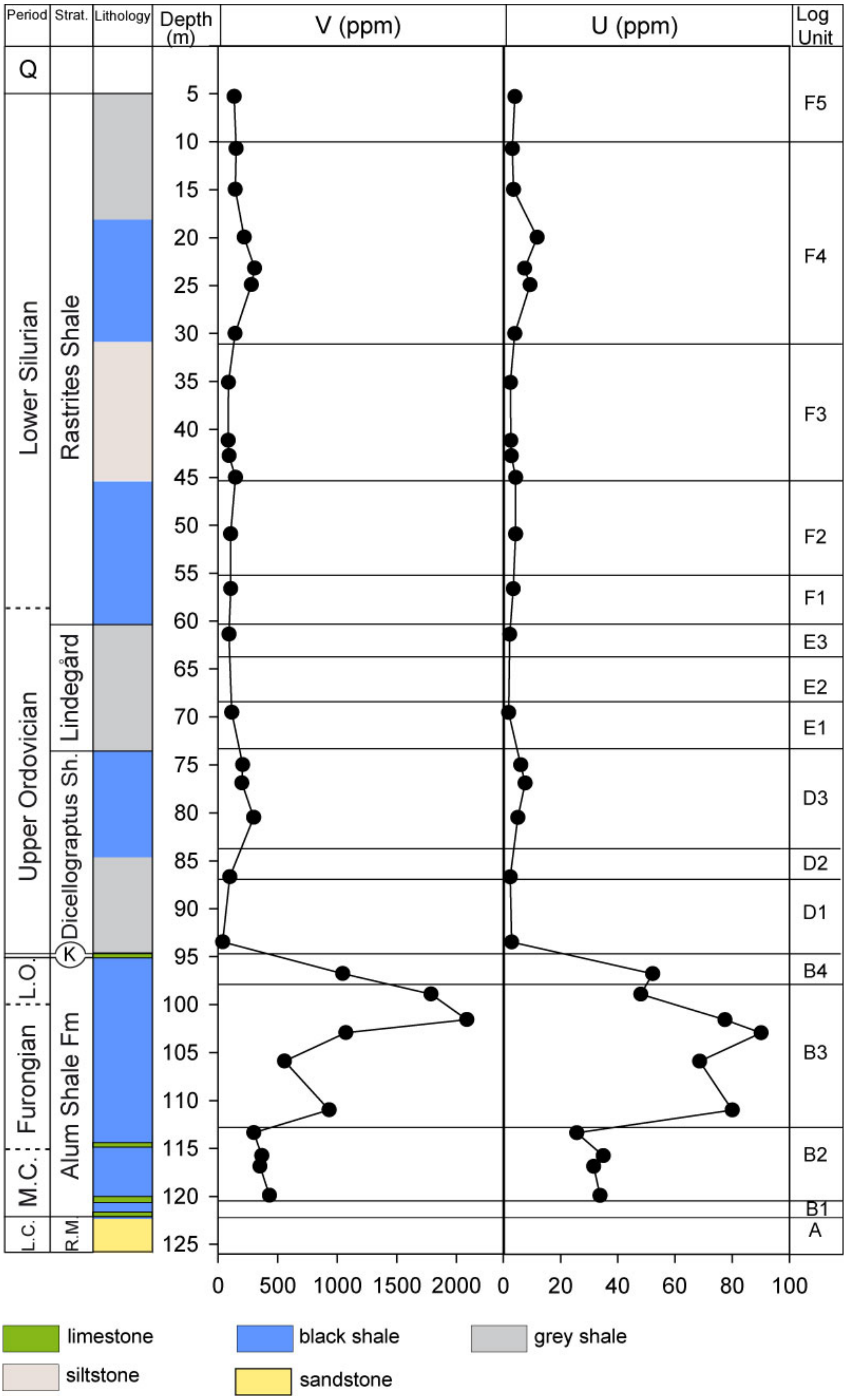


Figure 14. Stratigraphical variation of the U and V content in the Billegrav-2 well. Lithology and stratigraphy after Schovsbo et al. (2011).

Table 7. Selected trace element concentrations ('REE method'). The 36 elements measured by the REE method and the 56 elements measured by the TotalQuant methods are presented in Appendix B.

Formation	Unit	Depth	TOC	V	Cr	Ni	Ba	Th	U	V/(V+Ni)
		Base, m	%	ppm	ppm	ppm	Ppm	ppm	ppm	
Rastrites	F5	5.28	1.0	135	82	87	395	10	4	0.61
Rastrites	F4	10.70	0.5	151	87	72	400	11	3	0.68
Rastrites	F4	14.97	0.5	145	84	75	390	11	4	0.66
Rastrites	F4	19.95	3.9	219	58	101	354	7	12	0.68
Rastrites	F4	23.18	2.3	307	84	84	370	8	7	0.78
Rastrites	F4	24.90	3.1	279	135	131	364	10	9	0.68
Rastrites	F4	29.99	1.2	142	137	56	371	11	4	0.72
Rastrites	F3	35.10	0.6	87	98	50	302	8	2	0.64
Rastrites	F3	41.15	0.9	84	112	48	282	9	3	0.64
Rastrites	F3	42.74	1.0	93	107	61	303	9	3	0.60
Rastrites	F3	45.00	0.8	145	85	83	386	10	4	0.64
Rastrites	F2	50.90	1.1	105	107	76	347	9	4	0.58
Rastrites	F1	56.60	0.4	107	104	61	339	10	3	0.64
Lindegård	E3	61.37	0.2	92	97	63	302	8	2	0.59
Lindegård	E1	69.53	0.2	115	212	172	361	11	2	0.40
Dicellograptus	D3	74.99	2.0	207	154	82	370	10	6	0.72
Dicellograptus	D3	76.89	3.1	199	195	128	314	7	8	0.61
Dicellograptus	D3	80.47	3.9	299	124	99	296	7	5	0.75
Dicellograptus	D2	86.68	0.7	98	112	66	368	7	2	0.60
Dicellograptus	D1	93.47	0.7	38	31	29	293	8	3	0.57
Alum	B4	96.76	6.7	1045	69	137	443	12	52	0.88
Alum	B3	98.90	7.1	1786	80	281	8524	12	48	0.86
Alum	B3	101.57	9.5	2086	81	394	834	12	78	0.84
Alum	B3	102.93	11.3	1071	69	185	3288	15	90	0.85
Alum	B3	105.90	10.1	558	63	111	2297	12	69	0.83
Alum	B3	110.98	8.4	931	69	243	9322	12	80	0.79
Alum	B2	113.35	7.9	300	69	70	864	14	26	0.81
Alum	B2	115.75	8.8	366	72	84	704	14	35	0.81
Alum	B2	116.86	7.3	351	72	85	711	14	32	0.80
Alum	B2	119.90	5.2	432	74	97	680	14	34	0.82

7. Geotechnical measurements

The samples were prepared for three different tests; unconfined compression test, Brazil test and acoustic measurements. The specimen preparation varied for the three test types (Table 8). The analyses were made by the Danish Geotechnical Institute (GEO). The acoustic measurements were made at GEO and interpreted at the Danish Technical University (DTU) by Pernille Birkelund on behalf of GEUS. Details on the setup and results of the test program are presented in Appendix C and D.

Table 8. Overview of the sample program and test specimens.

Formation	Acoustic velocity measurements		Unconfined compres-sion test		Brazil tests	
	Plug samples	Test spec-imens	Plug samples	Test spec-imens	Plug samples	Test spec-imens
Rastrites	8	18	4	4	2	3
Lindegård	1	3	0	0	0	0
Dicellograptus	2	7	1	3	1	2
Alum	6	14	2	4	3	5
Total	17	42	7	11	6	10

7.1. Rock strength

<u>Tensile strength</u>
The tensile strength was determined on 10 samples following the Brazilian test setup. The tensile strength range from 2.35-6.19 Mpa (Table 9). One sample gave a very high value of 11.47 Mpa. This measurement is regarded as incorrect probably due to the mounting of the sample – a sub-sample was re-measured and gave a compression strength of 4.69 Mpa (Table 9).

<u>Compression strength</u>
The compression strength range between 17.7-67.5 Mpa (Table 9). Highest compression strength was measured in the Rastrites Shale and lowest compression strength was measured in the Alum Shale. The high compression strength in the Rastrites shale may be related to its high quarts content (Figure 15A).

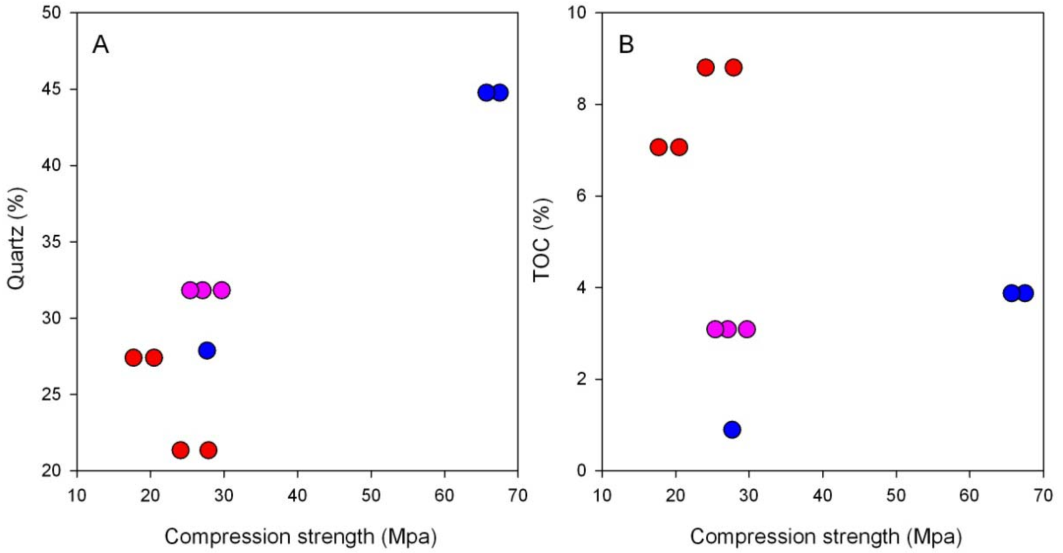


Figure 15. Relationship between compression strength and (A) quartz content and (B) TOC content. Legend: red: Alum Shale, pink: Dicellograptus Shale, green: Lindegård Fm., blue: Rastrites Shale.

Table 9. Results for tensile (σt) and compression (σc) tests results. The Youngs module (E) and Poisson ratio (V) was measured during testing. Measurement in () indicate an abnormal high measurement. Sample depth represents position in the core plug.

Lab no	Depth	Formation	ρ bulk	Moisture	σt	σt	σc	E	V
	m		g/cm3	%	MPa	PSI	MPa	MPa	MPa
4A	19.87	Rastrites	2.48	3.2			67.5	10129	0.29
4B	19.87	Rastrites	2.48	2.8			65.7	9874	0.14
5	23.18	Rastrites	2.5	2.5	2.63	381			
9A	41.02	Rastrites	2.61	2			19.2	6170	0.08
9B	41.2	Rastrites	2.6	1.9			27.7	5847	0.22
10A	42.74	Rastrites	2.57	2.4	2.75	399			
10B	42.74	Rastrites	2.57	2.5	6.19	898			
17A	76.82	Dicellograptus	2.51	2.8			27.1	5144	0.06
17B	76.85	Dicellograptus	2.49	2.9			25.4	7090	0.09
17C	76.85	Dicellograptus	2.47	2.8			29.7	3183	
19A	86.68	Dicellograptus	2.63	1.5	(11.47)	(1663)			
19B	86.68	Dicellograptus	2.59	1.7	4.69	680			
21A	96.76	Alum	2.45	2.6	4.32	626			
21B	96.76	Alum	2.47	2.6	3.37	489			
22C	98.81	Alum	2.46	2.6			17.7	5324	0.24
22A	98.86	Alum	2.49	2.7			20.5	4588	0.2
24A	102.93	Alum	2.47	3.3	2.35	341			
24B	102.93	Alum	2.56	3.2	4.46	647			
27	113.35	Alum	2.51	2.7	3.52	511			
28A	115.67	Alum	2.68	2.5			24.1	5757	0.14
28B	115.67	Alum	2.61	2.4			27.9	6402	0.21

7.2. Vp and Vs measurements

Acoustic measurements were preformed in three directions (45^o angle, vertical and horizontal) relative to bedding. Compression and shear wave velocities (Vp, Vs1 and Vs2) were measured. Due to technical errors in the analytical set-up the Vp and Vs measurements made in June 2011 were discarded and re-measured in Marts 2012. The measurements were made at low (3-5 Mpa) and high (7-10 Mpa) confining pressures. In general two measurements were made at each pressure step. In appendix D all measurements are presented. Full list of the analytical results are presented in Appendix D in the folder 'sound measurements'.

Vp measurements

The average of the Vp measurements made at low confining pressures (5-7 Mpa) and at high (7-10 Mpa) confining pressures are almost identical (Figure 16). This indicates that the samples has a low compressibility and also that the analytical precision is relative low.

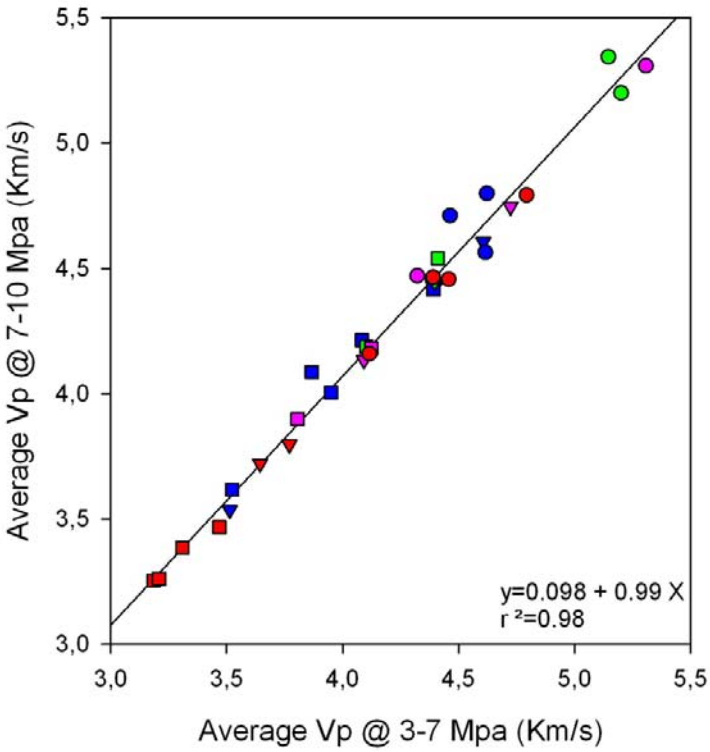


Figure 16. Relationship between core plug measurements of Vp at low and high confining pressures. Legend: shape of symbols: circles: horizontal to bedding, squares: vertical to bedding, triangles: 45^o angle to bedding. Colours: red: Alum Shale, pink: Dicellograptus Shale, green: Lindegård Fm., blue: Rastrites Shale.

The measured VP show the same overall trend as the sonic velocities measured in the bore hole (Figure 17). The Vp velocities varies between 3.2-5.3 Km/s in the Alum Shale (Figure 17). The highest velocities are measured systematically in the horizontal direction and lowest velocities are measured in the vertical direction. The velocity measured at a 45^o angle plot with intermediate values (Figure 17). This suggests that the shale is strongly anisotrope with regard to the velocities.

The Vp measurements varies between 3.5-5.2 Km/s in the Dicellograptus, Lindegård and Rastrites shales (Figure 17). The same systematics as seen in the Alum Shale can be observed i.e. that the horizontal velocity is larger than velocity measured at 45^o angle which is larger than then velocity measured in vertical direction.

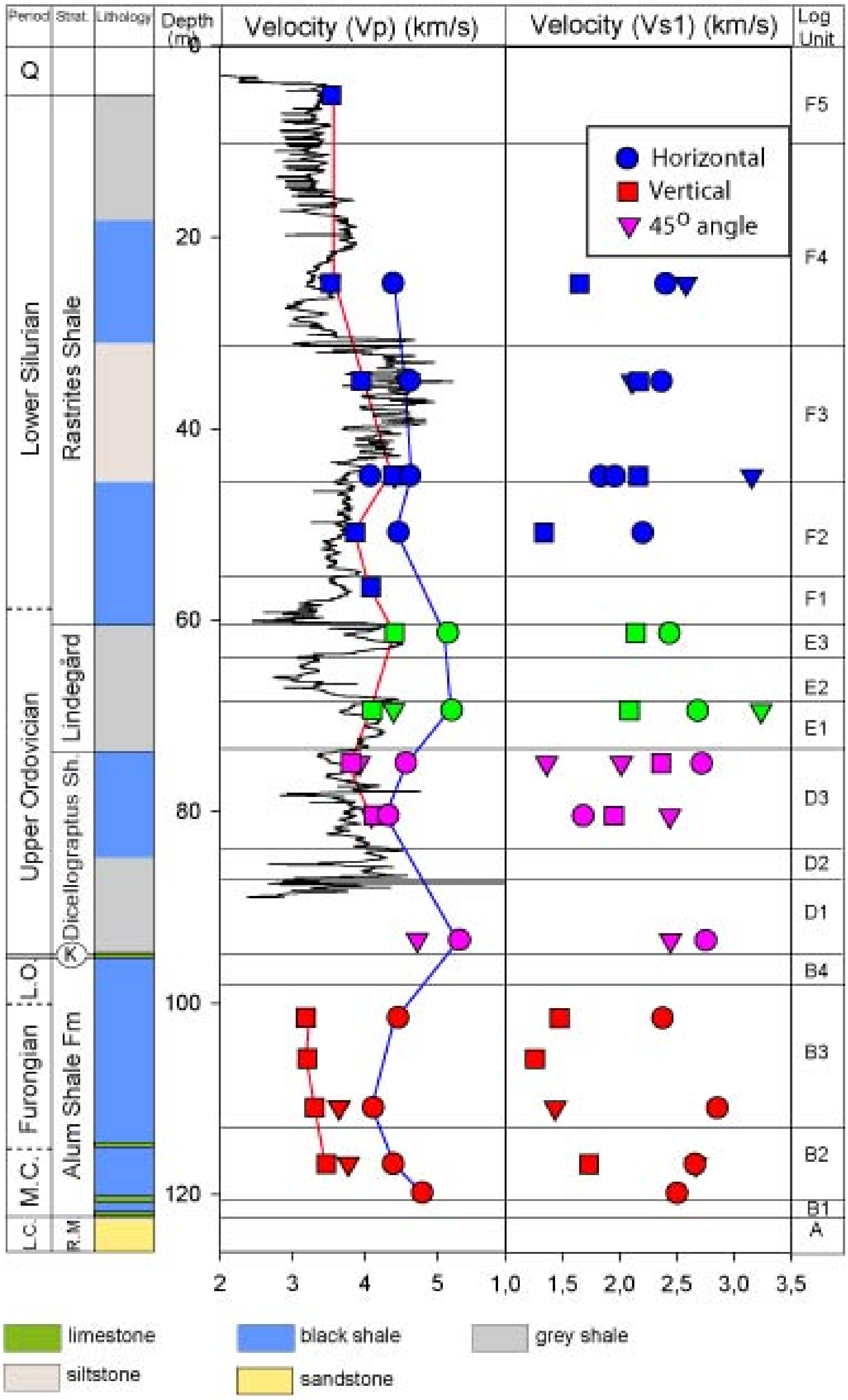


Figure 17. Stratigraphical variation of average Vp @ 3-7 Mpa confining pressure (A) and average Vs1 @ 5-7 Mpa (B) in the Billegrav-2 well. The sonic log obtained in the hole (Schovsbo et al. 2011) is shown for comparison. Lithology and stratigraphy after Schovsbo et al. (2011). Blue line in A combine Vp in horizontal direction, whereas red line in A combine Vp measured in vertical direction. Colours: red: Alum Shale, pink: Dicellograptus Shale, green: Lindegård Fm., blue: Rastrites Shale.

Vs measurements

Vs measurements are presented in Figures 17 and 18 and in Appendix D. Two measurements were made: Vs1 and Vs2. The two measurements represent velocities at right angel to each other. The Vs velocities at low and high pressure steps show higher degree of scatter than for the Vp measurements (compare figure 16 and 18). This reflects partly the higher measuring uncertainties that exist on the Vs measurements than on the Vp measurements.

The Vs velocities measured at low pressure step is slightly slower than the velocities measured at the high pressure step (Figure 18). This indicate that the Vs velocities increase with increasing depth.

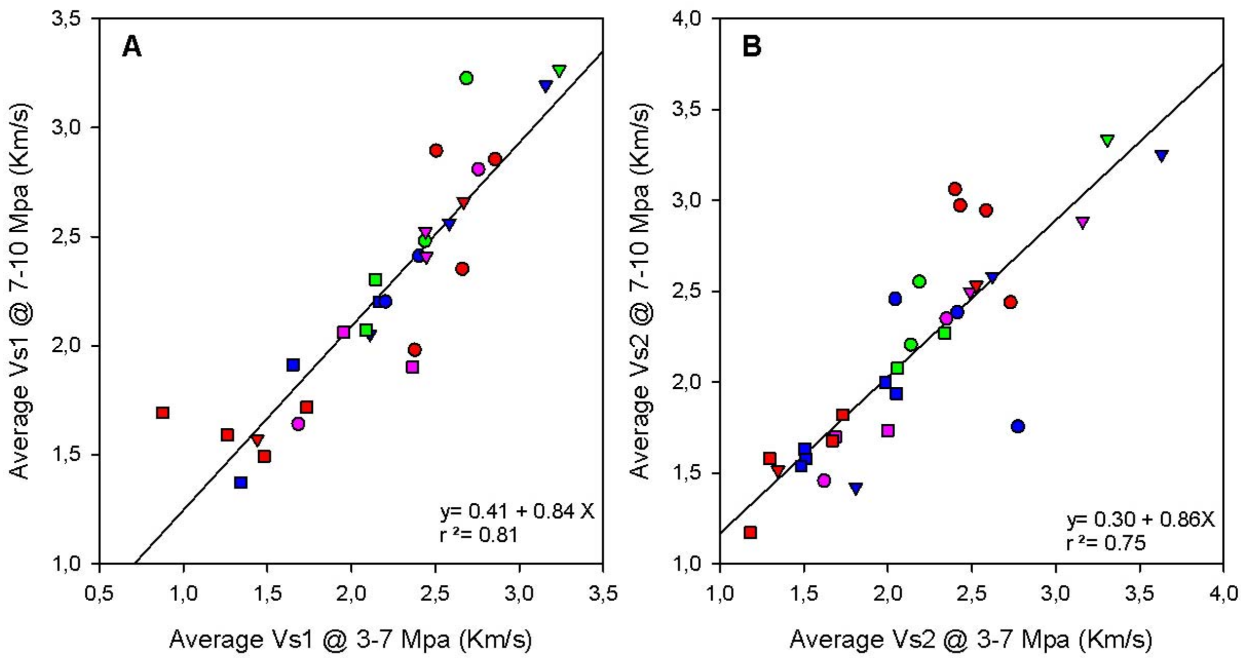


Figure 18. Relationship between core plug measurements of (A) Vs1 at 3-7 Mpa confining pressure and at 7-10 Mpa confining pressure (A) and (B) Vs2 at 3-7 Mpa confining pressure and at 7-10 Mpa confining pressure for. Legend: shape of symbols: circles: horizontal to bedding, squares: vertical to bedding, triangles: 45^{o} angle to bedding. Colours: red: Alum Shale, pink: Dicellograptus Shale, green: Lindegård Fm., blue: Rastrites Shale.

The relationship between Vp and Vs is shown in Figure 19. The variation indicate that the samples have a large range in Vp/Vs ratio compared to the mud rock line of Castagna et al. (1985).

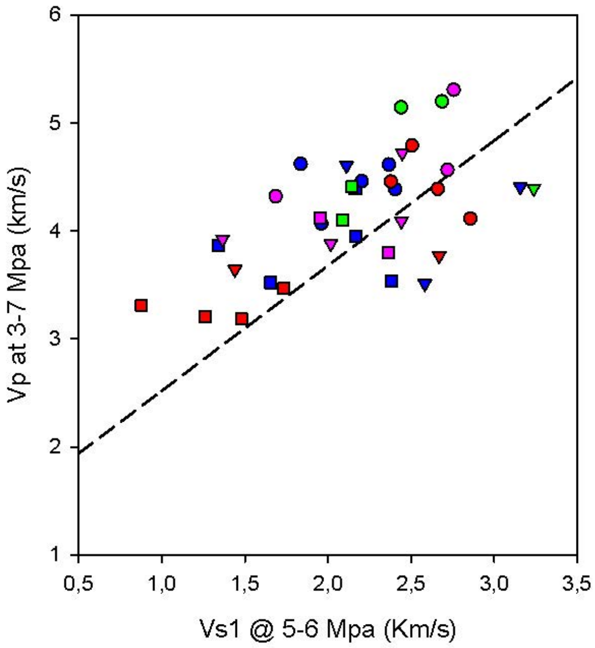


Figure 19. Relationship between core plug measurements of VP and Vs1. Legend: shape of symbols: circles: horizontal to bedding, squares: vertical to bedding, triangles: 45^{o} angle to bedding. Colours: red: Alum Shale, pink: Dicellograptus Shale, green: Lindegård Fm., blue: Rastrites Shale. The mud-rock line (Vp=1.16Vs +136) is shown with broken line for reference (Castagna et al. 1985).

8. References

Andersson, A., Dahlman. B., Gee, D.G., Snäll, S., 1985. The Scandinavian Alum Shale. SGU Serie Ca 56, 1–50.

Schovsbo, N.H., Nielsen, A.T., Klitten, K., Mathiesen, A., Rasmussen, P., 2011. Shale gas investigations in Denmark: Lower Palaeozoic shales on Bornholm. Geological Survey of Denmark and Greenland Bulletin 23, 9–14.

Buchardt, B., Clausen, J., Thomsen, E., 1986. Carbon isotope composition of Lower Palaeozoic kerogen: Effects of maturation. Organic geochemistry 10, 127–134.

Castagna, J.P., Batzle, M.L., Eastwood, R.L. 1985. Relationships between compressional-wave and shear-wave velocities in clastic silicate rocks Geophysics 50, 571–581.

Schovsbo, N.H., 2001. Why barren intervals barren? A taphonomic case study of the Scandinavian Alum Shale and its faunas. Lethaia 34, 271–285.

Schovsbo, N.H., 2002. Uranium enrichment shorewards in black shales: A case study from the Scandinavian Alum Shale. GFF 124, 107–116.

Schovsbo, N.H., 2011a. Completion report Billegrav-2 well (DGU 248.61) Part 1: Down hole logs, core scanning data and core photos. Geological Survey of Denmark and Greenland Report 2011/53, 1–18.

Schovsbo, N.H., 2011b. Completion report Billegrav-2 well (DGU 248.61) Part 2: Review of Skelbro-1 and Billegrav-1. Geological Survey of Denmark and Greenland Report 2011/79, 1–32.

Schovsbo, N.H., 2011c. Maturity database for the Lower Palaeozoic in Scandinavia. Geological Survey of Denmark and Greenland Report 2011/137, 1–19.

Jakobsen, P.R., Schovsbo, N.H., 2012. Completion report Billegrav-2 well (DGU 248.61) Part 5: Fracture descriptions and mineralogical analysis. Geological Survey of Denmark and Greenland Report 2012/26, 1–31.

Nielsen, A.T., Schovsbo, N.H., 2012. Completion report Billegrav-2 well (DGU 248.61) Part 4: Stratigraphy and sedimentological description of the cored Lower Silurian – Lower Cambrian strata. Geological Survey of Denmark and Greenland Report 2012/18. Not yet paginated.

Pedersen, G.K., 1989, The sedimentology of Lower Palaeozoic black shales from the shallow wells Skelbro 1 and Billegrav 1. Bornholm. Denmark. Bulletin of the Geological Society of Denmark 37, 151–173.

Pedersen, G.K., Klitten, K., 1990. Anvendelse af gamma-logs ved korrelation af marine skifre i vandforsyningsboringer på Bornholm. Danmarks Geologisk Forening Årsskrift 1987–89, 21–35.

9. Data included on CD

Attached to this report is a CD that contains the following documentation:

1. In folder *Appendix:*
   a. Hg-injection data
   b. ICPMS-measurements
   c. Geotechnical report
   d. Vp and Vs measurements
   e. Pdf of XRD spectra (on CD only)
   f. Pdf of Rock Eval programs (on CD only)
2. In folder *Table* are Excel versions of tables presented in the report
3. A pdf of this report: Completion report Billegrav-2 (DGU 248.61) Part 3.pdf

Appendix A: Hg-injection measurements

All data collected during the experiments are presented in the file: 'Appendix A Hg injection data.xlsx' located in folder Appendix on the attached CD.

Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

Sample Identification	29	
Sample Depth	116,70	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,007	fraction

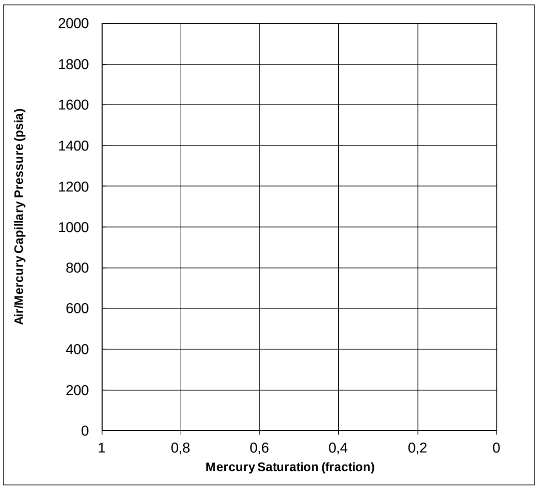
Injection Sample Porosity	0,013	fraction
Injection Sample Pore Vol	0,048	cc
Injection Sample Bulk Vol	3,803	cc
Injection Sample Weight	9,630	g

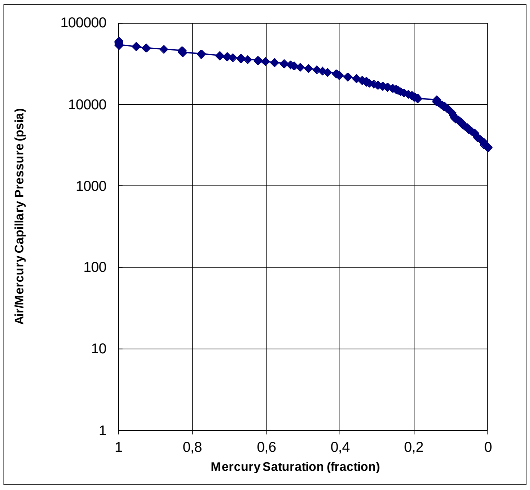
3,76 Grain Vol
2,56 Grain Density

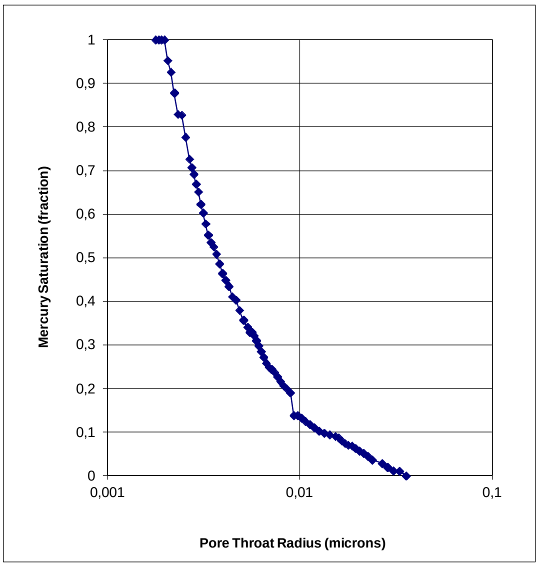
Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

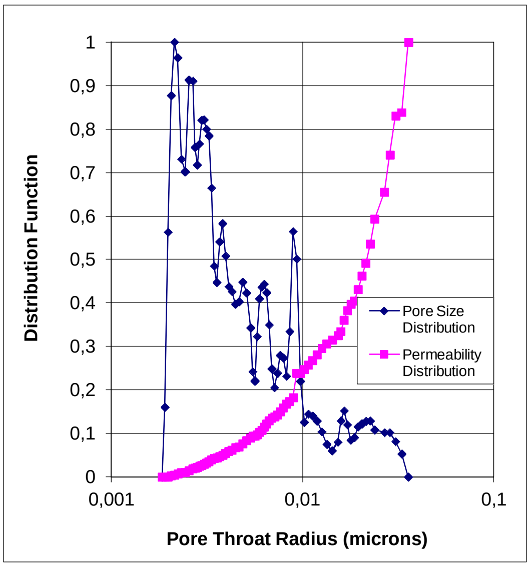
IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Mean Hydraulic Radius	0,006	microns
Swanson's Parameter	0,000	
FZI		









Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

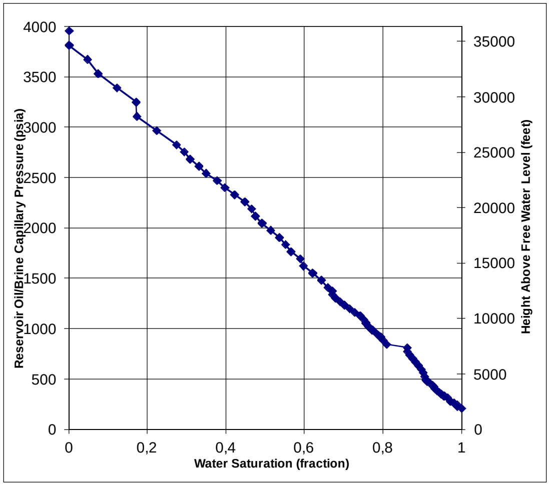
Sample Identification	29	
Sample Depth	116,70	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,007	fraction

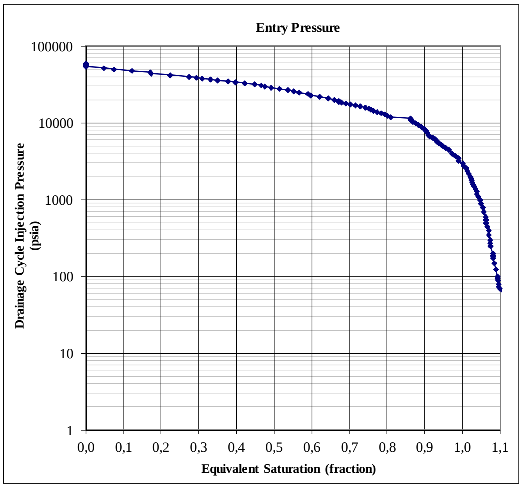
Injection Sample Porosity	0,013	fraction
Injection Sample Pore Vol	0,048	cc
Injection Sample Bulk Vol	3,803	cc
Injection Sample Weight	9,630	g

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Mean Hydraulic Radius	0,006	microns
Swanson's Parameter	0,000	
FZI		





Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

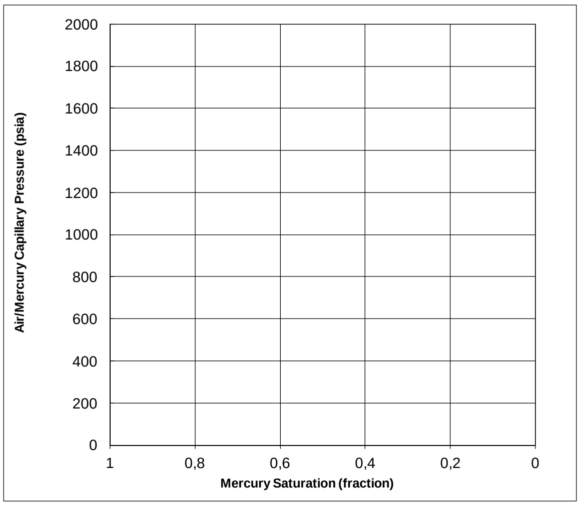
Sample Identification	27	
Sample Depth	113,30	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,004	fraction

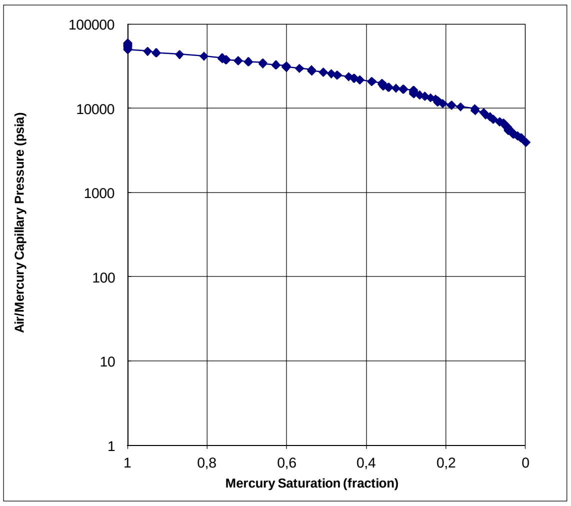
IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

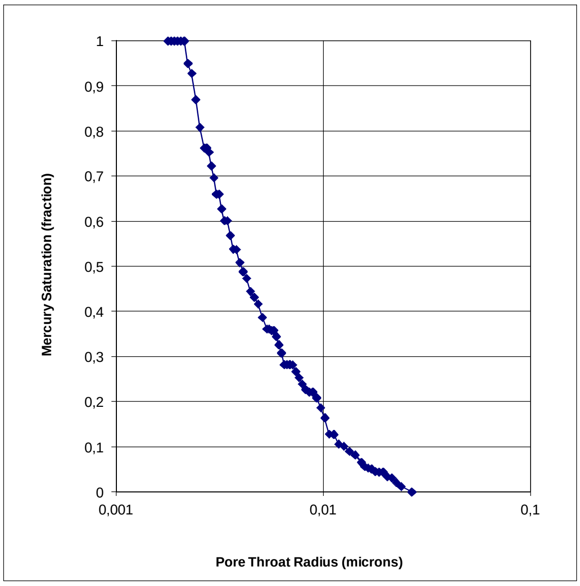
Injection Sample Porosity	0,012	fraction
Injection Sample Pore Vol	0,032	cc
Injection Sample Bulk Vol	2,606	cc
Injection Sample Weight	6,520	g

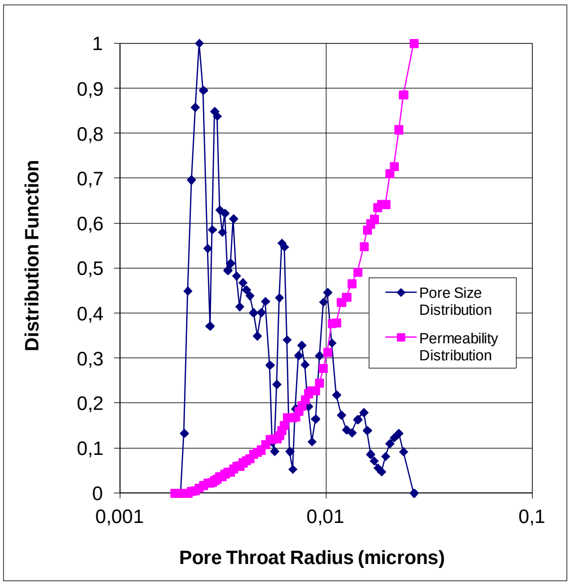
2,57	Grain Vol
2,53	Grain Density

Mean Hydraulic Radius	0,005	microns
Swanson's Parameter	0,000	
FZI		









Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

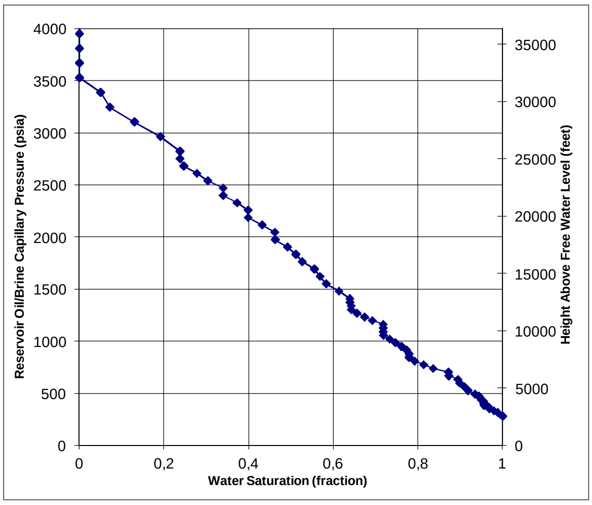
Sample Identification	27	
Sample Depth	113,30	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,004	fraction

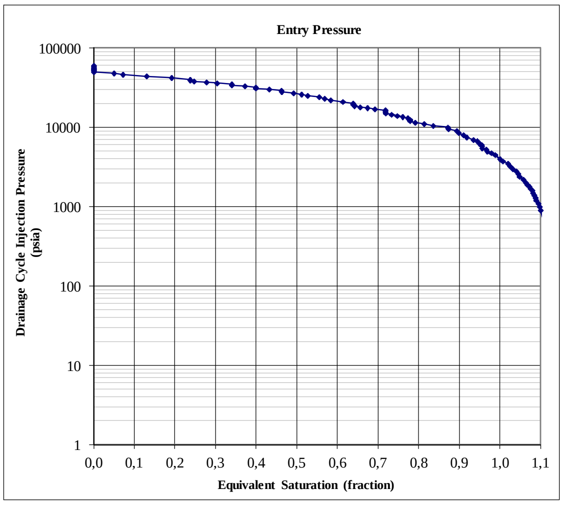
Injection Sample Porosity	0,012	fraction
Injection Sample Pore Vol	0,032	cc
Injection Sample Bulk Vol	2,606	cc
Injection Sample Weight	6,520	g

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Mean Hydraulic Radius	0,005	microns
Swanson's Parameter	0,000	
FZI		





Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

Sample Identification	26	
Sample Depth	110,90	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,005	fraction

Injection Sample Porosity	0,017	fraction
Injection Sample Pore Vol	0,044	cc
Injection Sample Bulk Vol	2,591	cc
Injection Sample Weight	6,270	g

2,55 Grain Vol
2,46 Grain Density

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

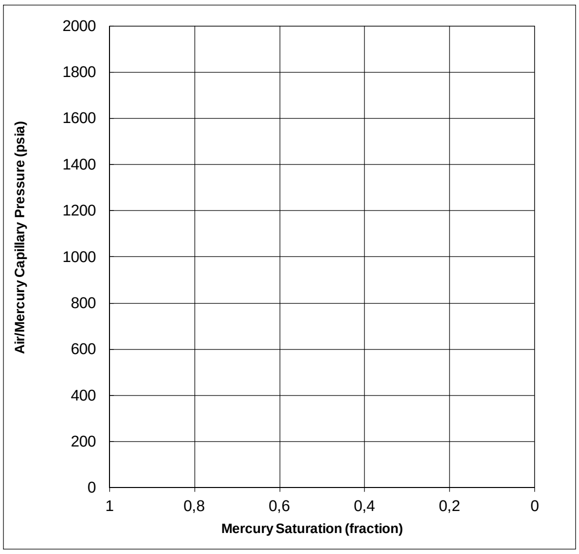
IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

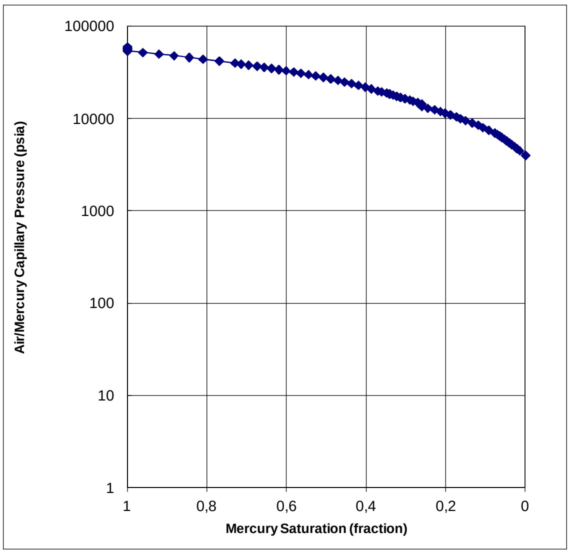
Mean Hydraulic Radius	0,005	microns
Swanson's Parameter	0,000	
FZI		

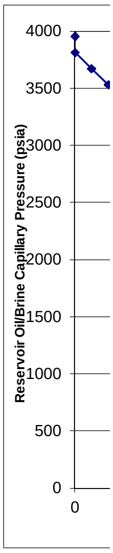
Client
Well
Reference

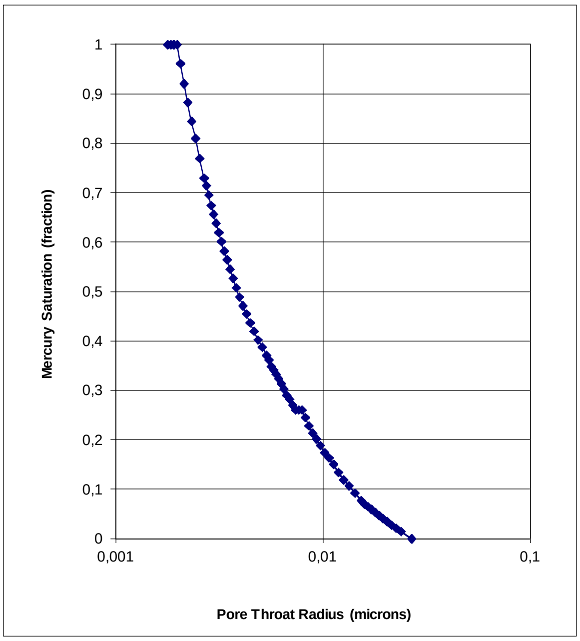
Sample Identi
Sample Depth
Plug Permeab
Plug Porosity

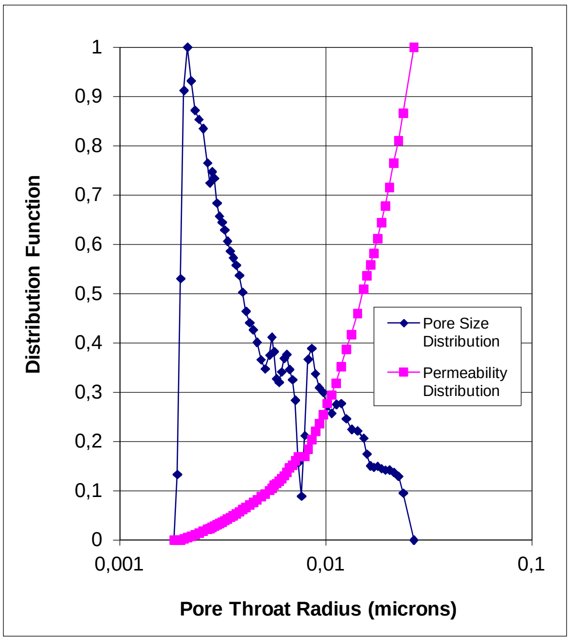
Injection Samp
Injection Samp
Injection Samp
Injection Samp











Mercury Injection

Geus
Billegrav-2
Shale Gas

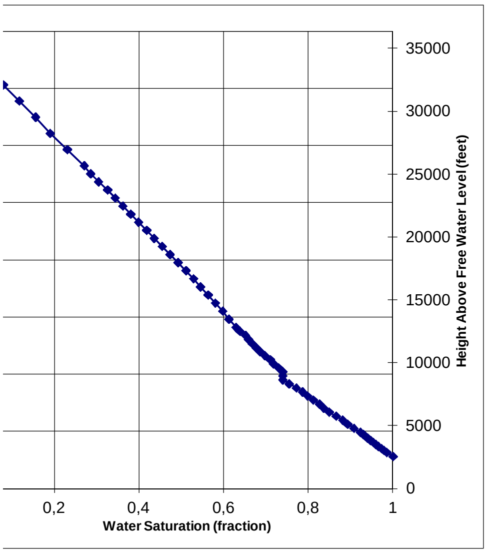
Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

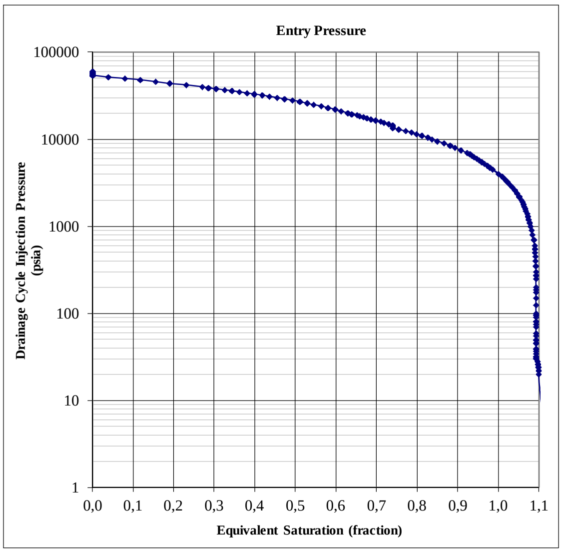
fication	26	
ı	110,90	m
ɔility (Air)	n/a	mD
(He)	0,005	fraction

IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

ɔle Porosity	0,017	fraction
ɔle Pore Vol	0,044	cc
ɔle Bulk Vol	2,591	cc
ɔle Weight	6,270	g

Mean Hydraulic Radius	0,005	microns
Swanson's Parameter	0,000	
FZI		





Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

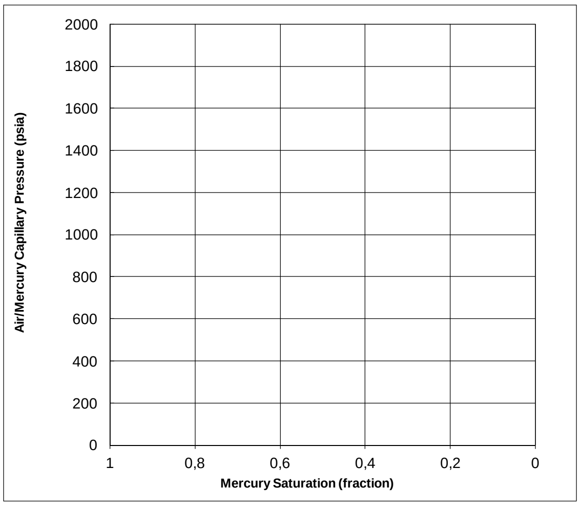
IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

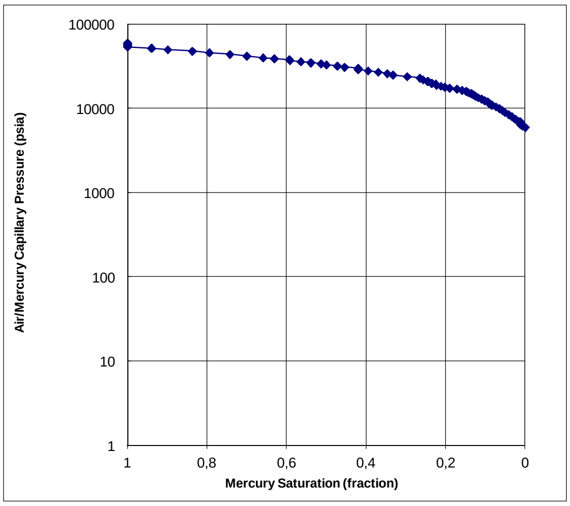
Sample Identification	25	
Sample Depth	105,80	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,011	fraction

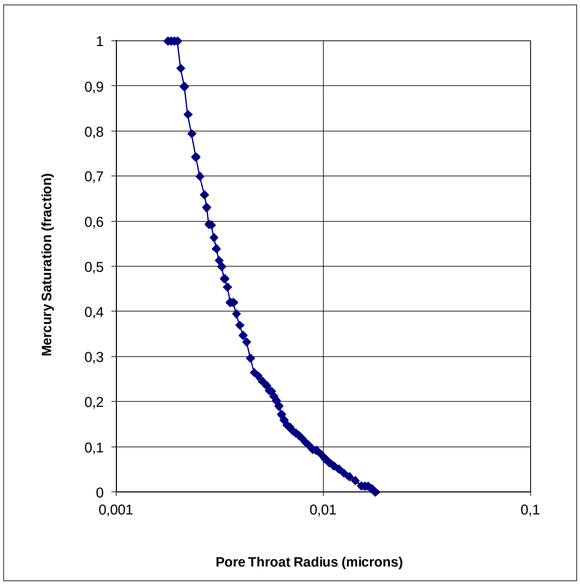
Injection Sample Porosity	0,019	fraction
Injection Sample Pore Vol	0,083	cc
Injection Sample Bulk Vol	4,261	cc
Injection Sample Weight	10,089	g

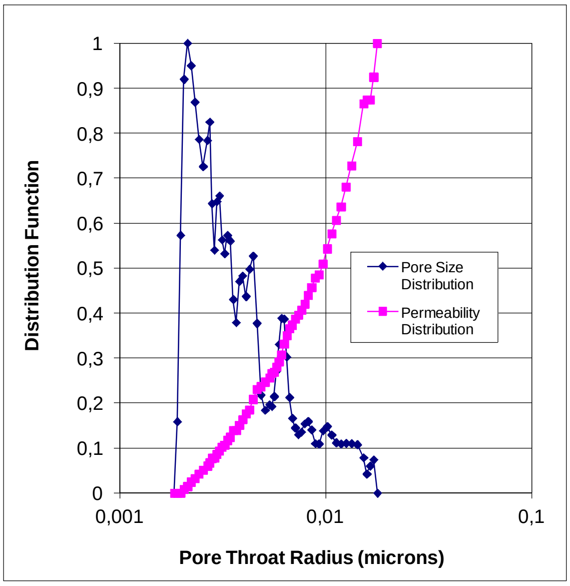
4,18 Grain Vol
2,41 Grain Density

Mean Hydraulic Radius	0,003	microns
Swanson's Parameter	0,000	
FZI		









Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

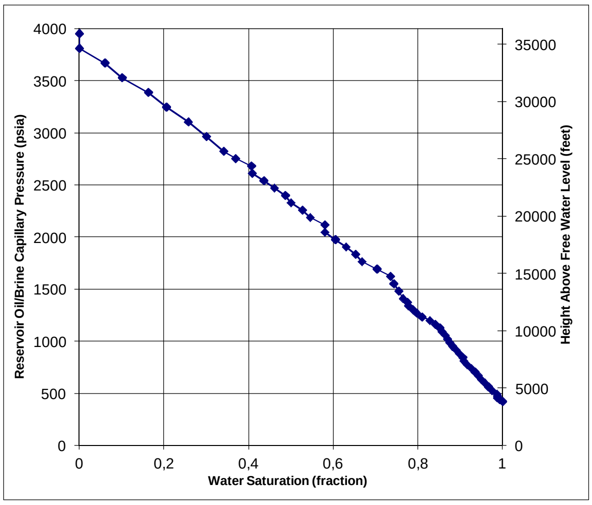
Sample Identification	25	
Sample Depth	105,80	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,011	fraction

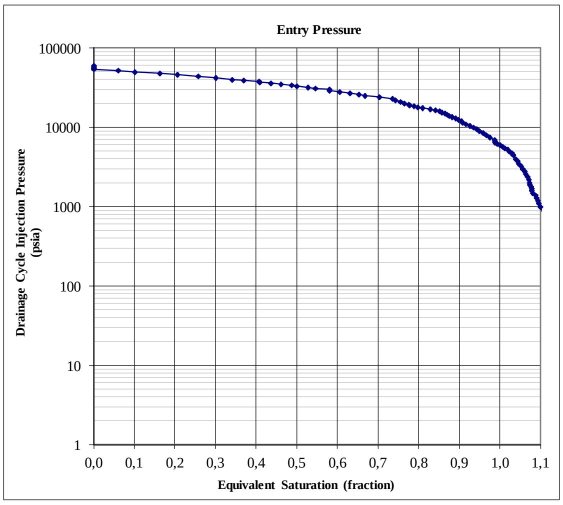
Injection Sample Porosity	0,019	fraction
Injection Sample Pore Vol	0,083	cc
Injection Sample Bulk Vol	4,261	cc
Injection Sample Weight	10,089	g

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Mean Hydraulic Radius	0,003	microns
Swanson's Parameter	0,000	
FZI		





Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

Sample Identification	23	
Sample Depth	101,50	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,016	fraction

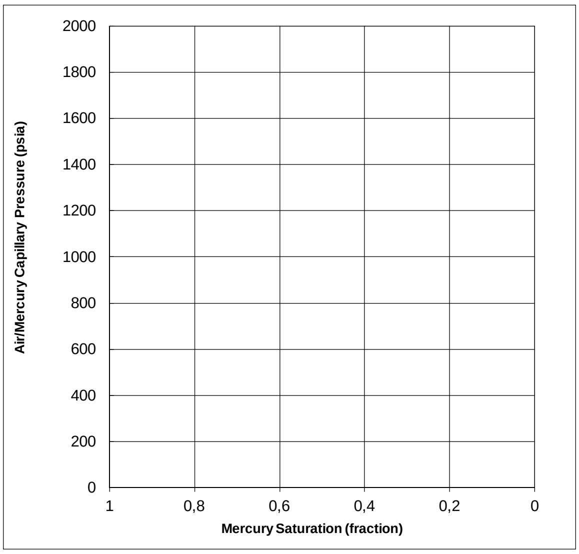
Injection Sample Porosity	0,016	fraction
Injection Sample Pore Vol	0,048	cc
Injection Sample Bulk Vol	2,914	cc
Injection Sample Weight	7,070	g

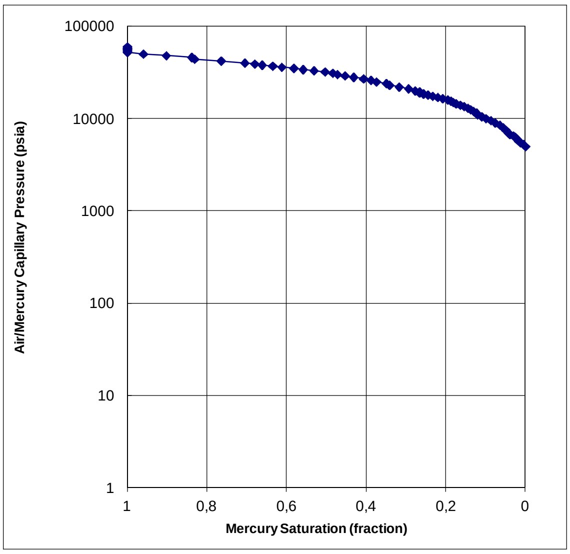
2,87 Grain Vol
2,47 Grain Density

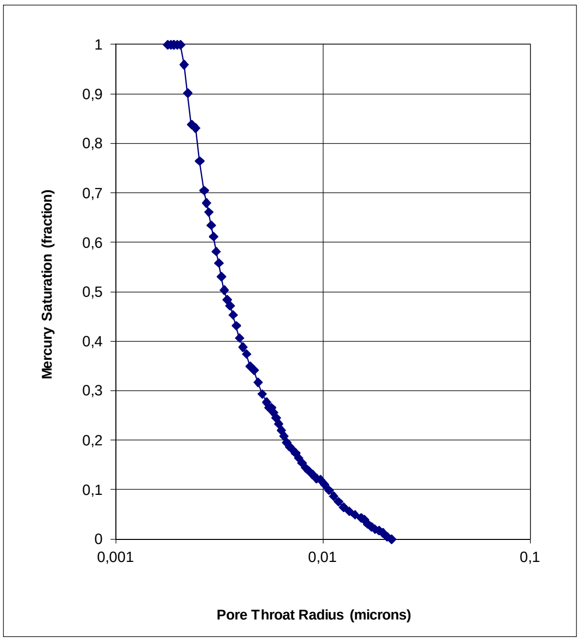
Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

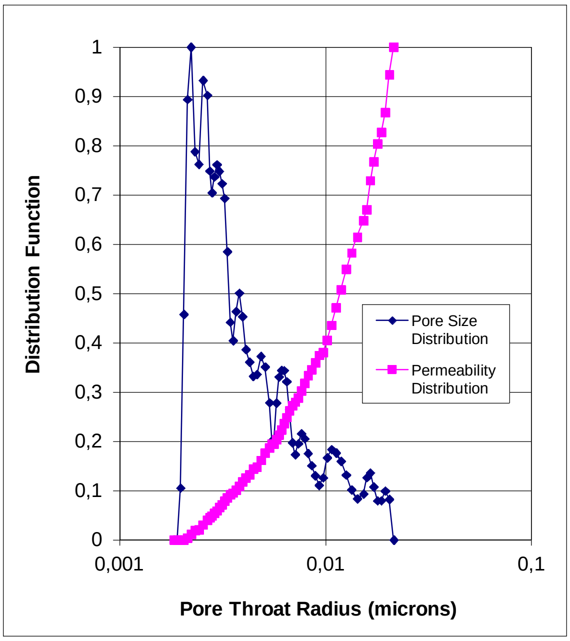
IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Mean Hydraulic Radius	0,004	microns
Swanson's Parameter	0,000	
FZI		









Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

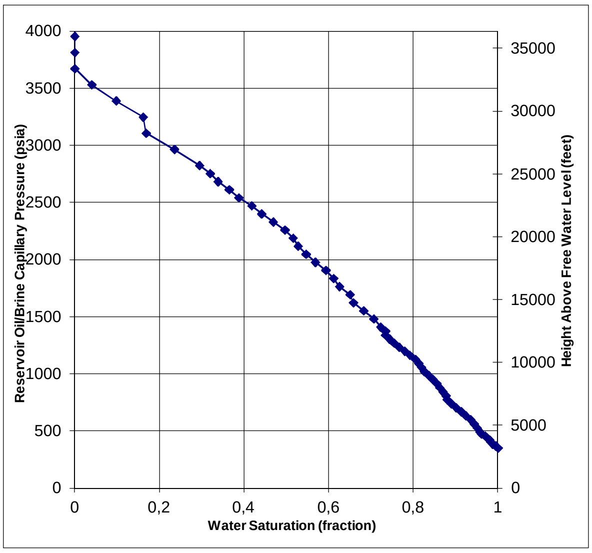
Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

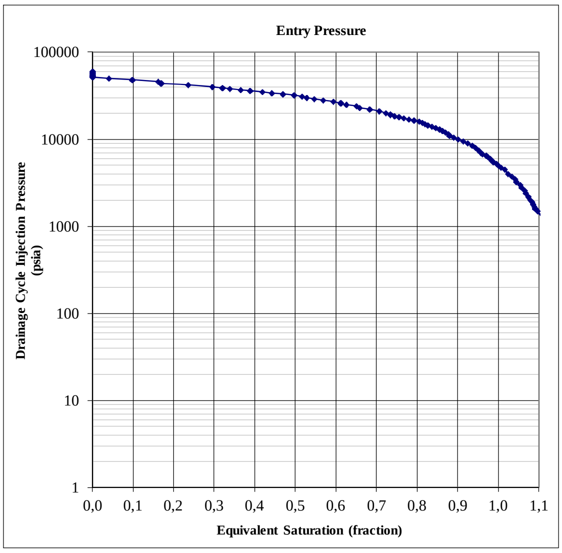
Sample Identification	23	
Sample Depth	101,50	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,016	fraction

IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Injection Sample Porosity	0,016	fraction
Injection Sample Pore Vol	0,048	cc
Injection Sample Bulk Vol	2,914	cc
Injection Sample Weight	7,070	g

Mean Hydraulic Radius	0,004	microns
Swanson's Parameter	0,000	
FZI		





Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

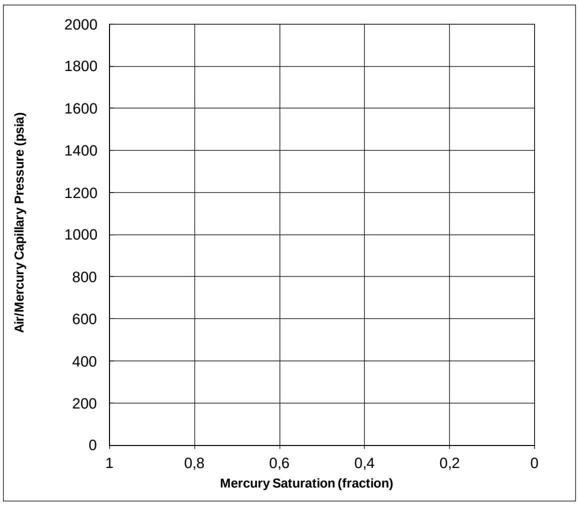
IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

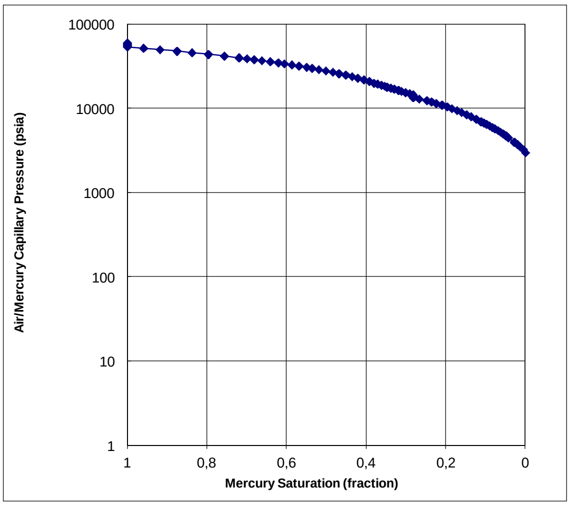
Sample Identification	18	
Sample Depth	80,40	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,0029	fraction

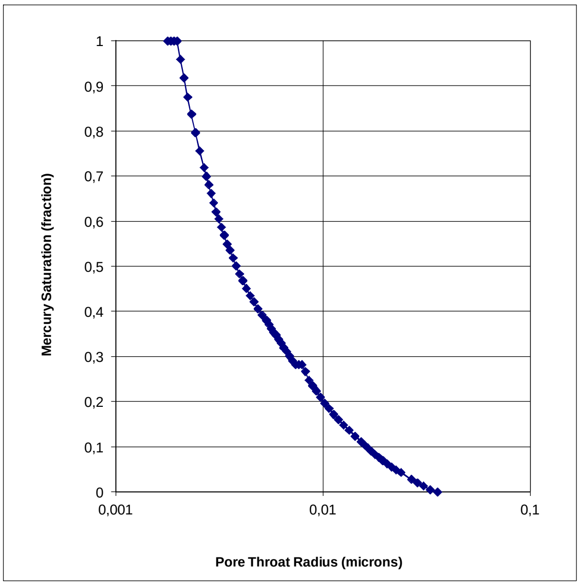
Injection Sample Porosity	0,011	fraction
Injection Sample Pore Vol	0,036	cc
Injection Sample Bulk Vol	3,119	cc
Injection Sample Weight	7,680	g

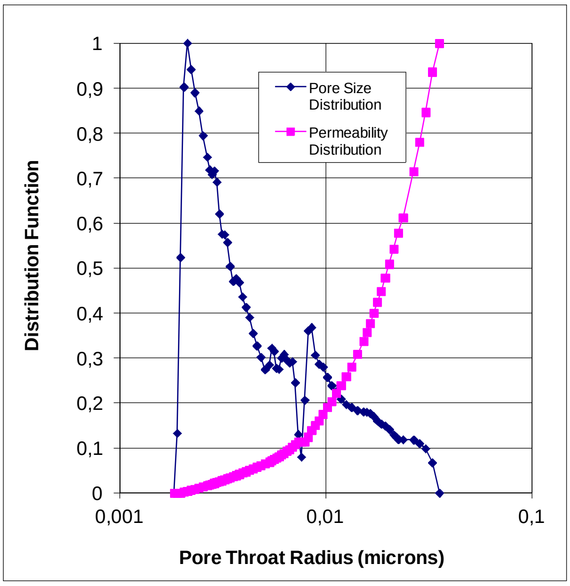
3,08 Grain Vol
2,49 Grain Density

Mean Hydraulic Radius	0,006	microns
Swanson's Parameter	0,000	
FZI		









Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

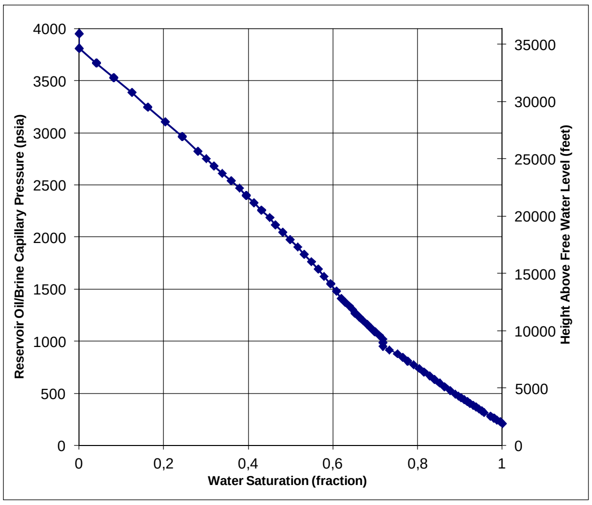
Sample Identification	18	
Sample Depth	80,40	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,0029	fraction

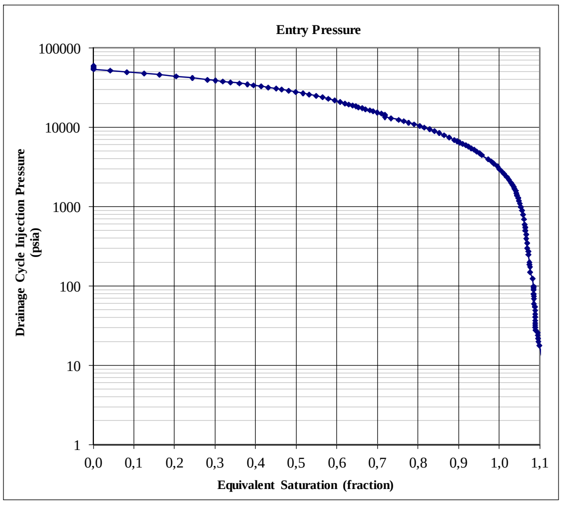
Injection Sample Porosity	0,011	fraction
Injection Sample Pore Vol	0,036	cc
Injection Sample Bulk Vol	3,119	cc
Injection Sample Weight	7,680	g

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Mean Hydraulic Radius	0,006	microns
Swanson's Parameter	0,000	
FZI		





Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

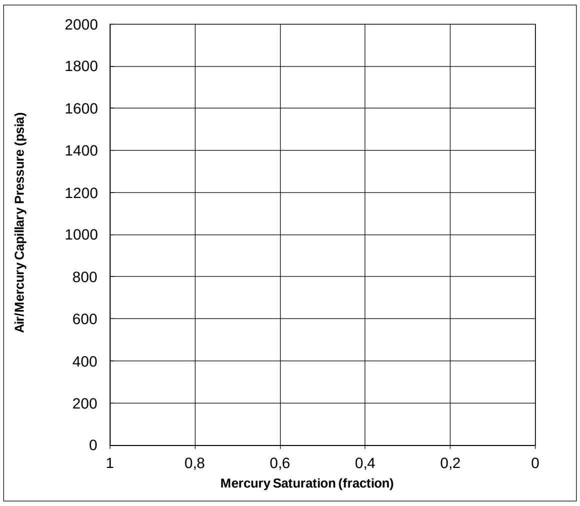
Sample Identification	16	
Sample Depth	74,90	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,02	fraction

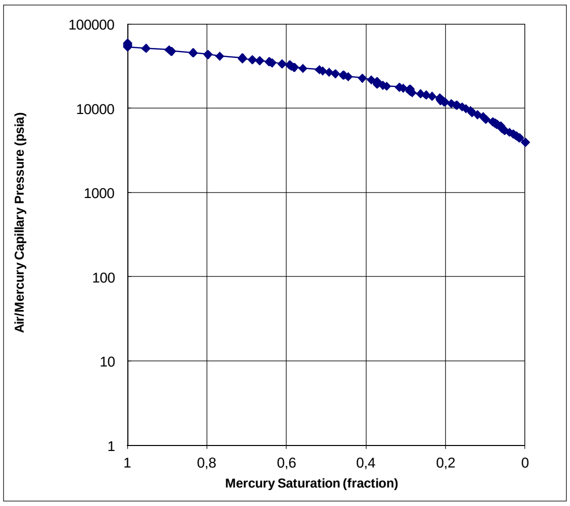
IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

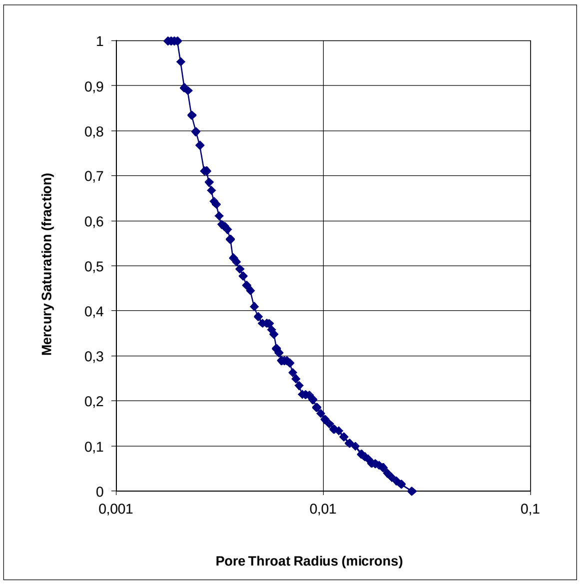
Injection Sample Porosity	0,021	fraction
Injection Sample Pore Vol	0,037	cc
Injection Sample Bulk Vol	1,727	cc
Injection Sample Weight	4,220	g

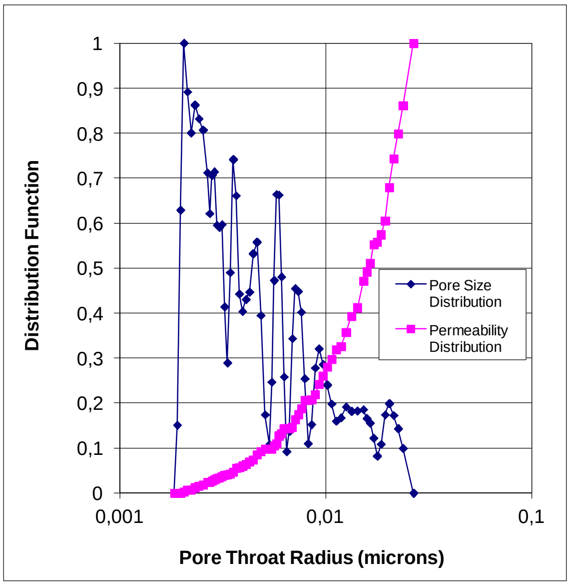
1,69 Grain Vol
2,50 Grain Density

Mean Hydraulic Radius	0,005	microns
Swanson's Parameter	0,000	
FZI		









Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

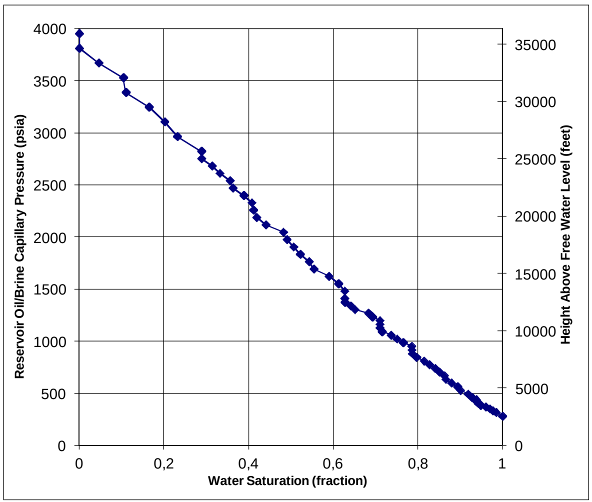
Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

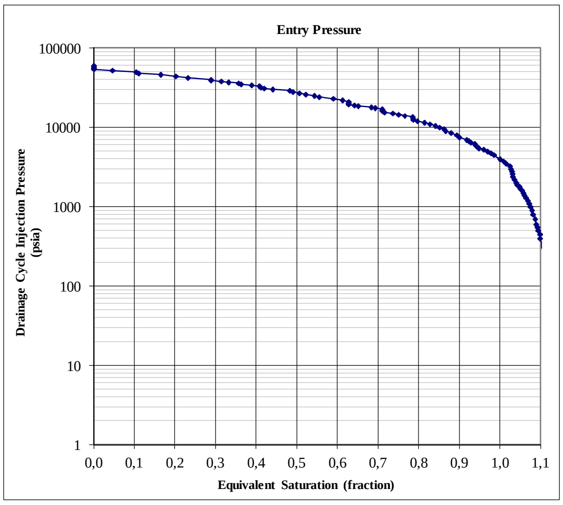
Sample Identification	16	
Sample Depth	74,90	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,02	fraction

IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Injection Sample Porosity	0,021	fraction
Injection Sample Pore Vol	0,037	cc
Injection Sample Bulk Vol	1,727	cc
Injection Sample Weight	4,220	g

Mean Hydraulic Radius	0,005	microns
Swanson's Parameter	0,000	
FZI		





Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

Sample Identification	10	
Sample Depth	42,65	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,0019	fraction

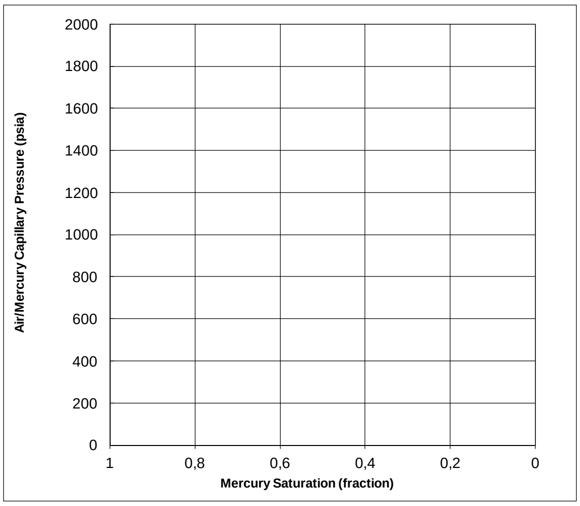
Injection Sample Porosity	0,017	fraction
Injection Sample Pore Vol	0,046	cc
Injection Sample Bulk Vol	2,660	cc
Injection Sample Weight	6,720	g

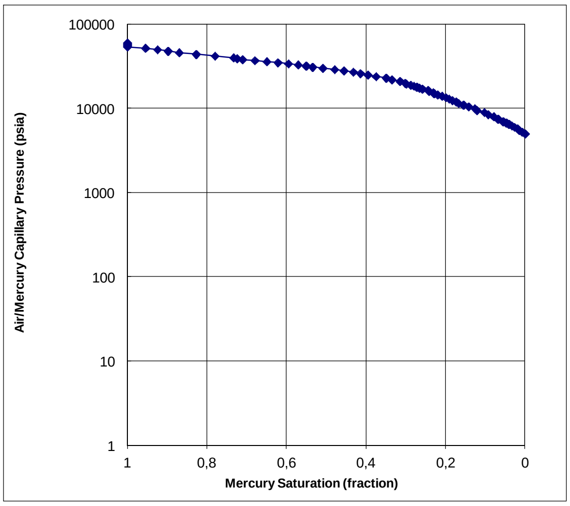
2,61 Grain Vol
2,57 Grain Density

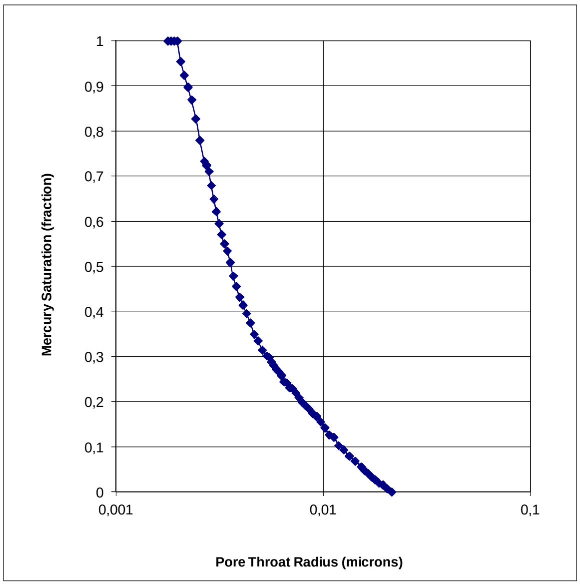
Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

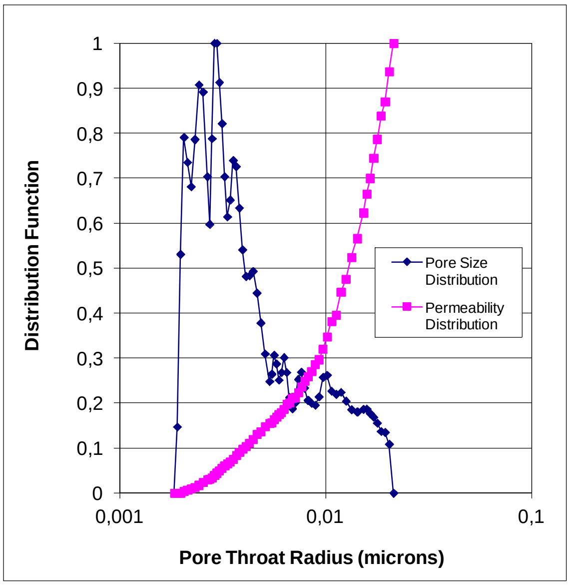
IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Mean Hydraulic Radius	0,004	microns
Swanson's Parameter	0,000	
FZI		









Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

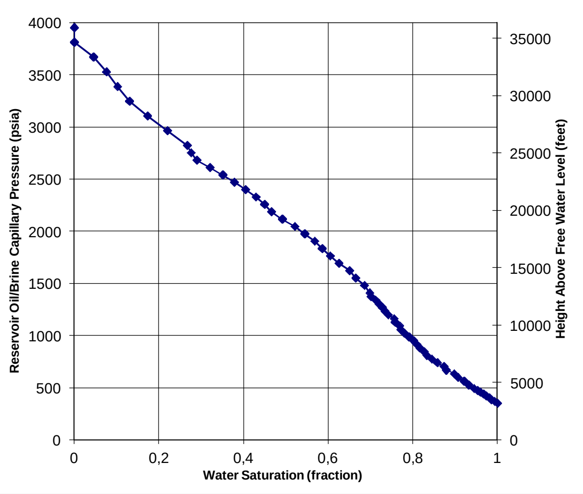
Sample Identification	10	
Sample Depth	42,65	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,0019	fraction

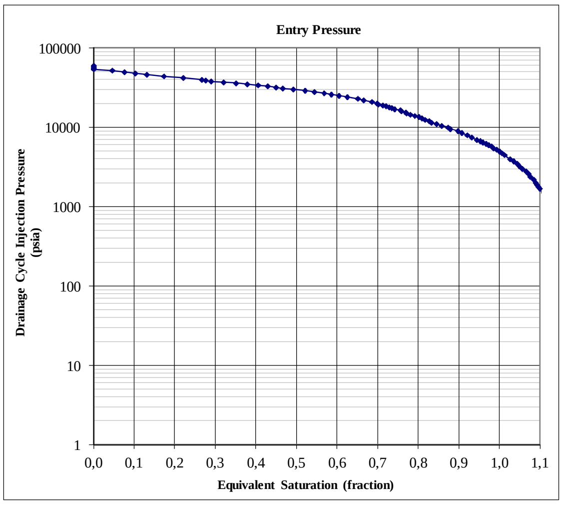
Injection Sample Porosity	0,017	fraction
Injection Sample Pore Vol	0,046	cc
Injection Sample Bulk Vol	2,660	cc
Injection Sample Weight	6,720	g

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Mean Hydraulic Radius	0,004	microns
Swanson's Parameter	0,000	
FZI		





Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

Sample Identification	7	
Sample Depth	29,90	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,039	fraction

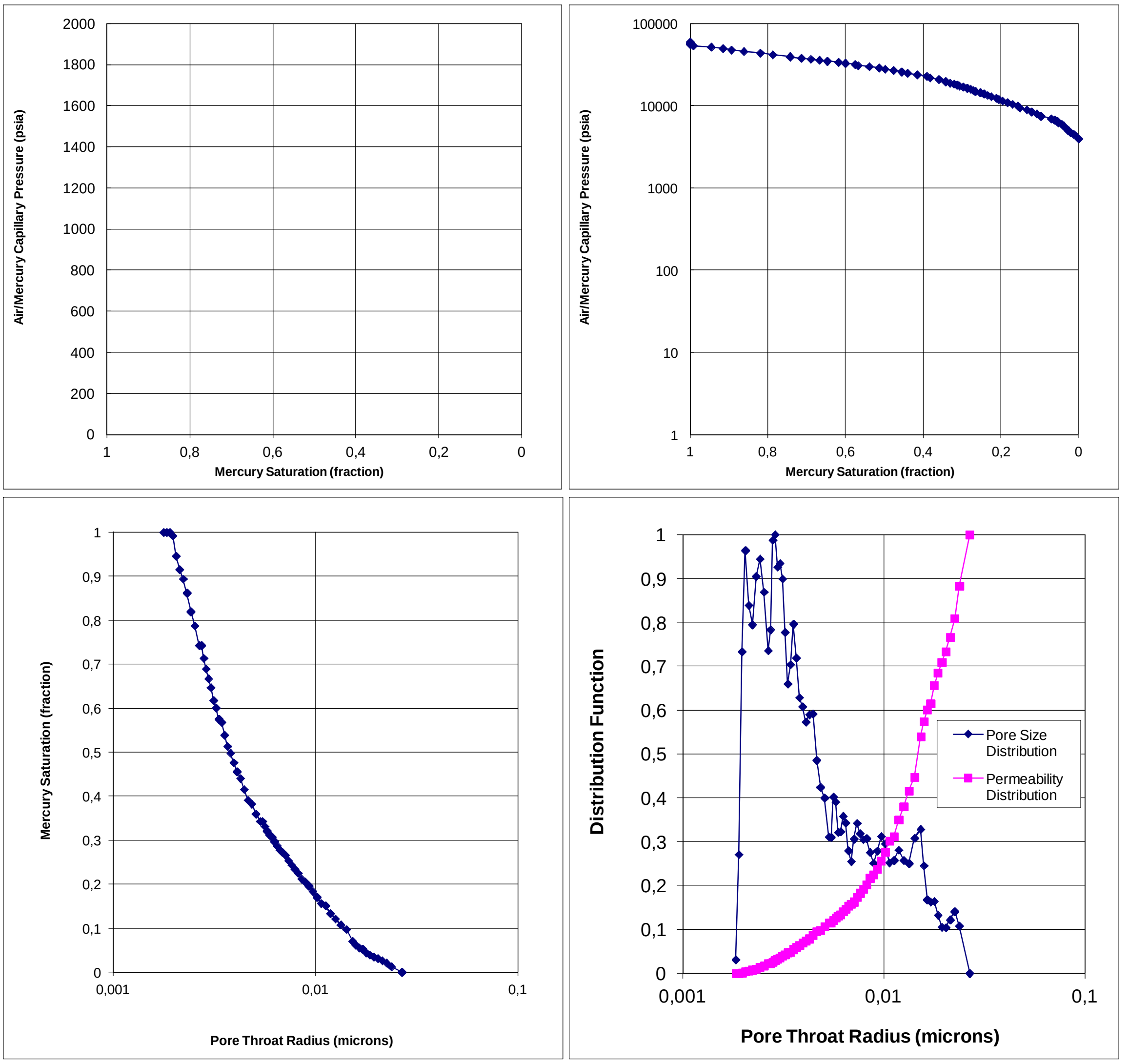
Injection Sample Porosity	0,024	fraction
Injection Sample Pore Vol	0,114	cc
Injection Sample Bulk Vol	4,822	cc
Injection Sample Weight	12,130	g

4,71	Grain Vol
2,58	Grain Density

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Mean Hydraulic Radius	0,005	microns
Swanson's Parameter	0,000	
FZI		



Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

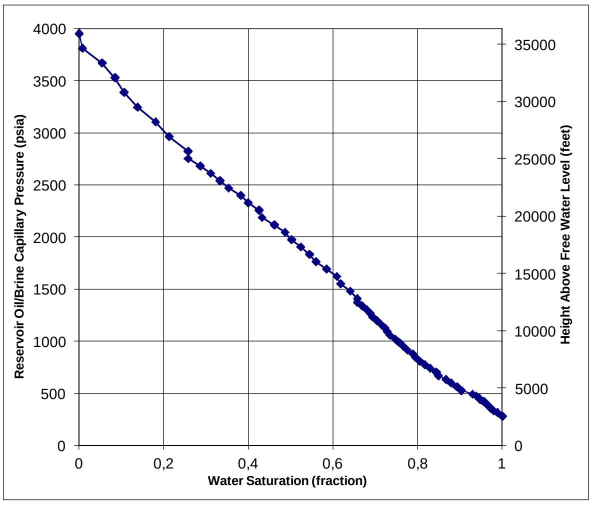
Sample Identification	7	
Sample Depth	29,90	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,039	fraction

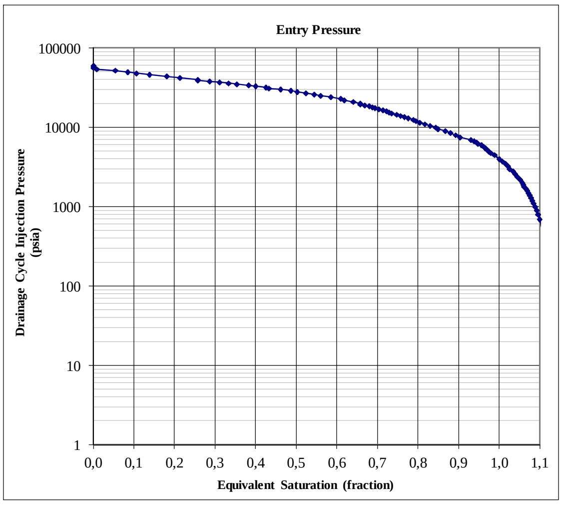
Injection Sample Porosity	0,024	fraction
Injection Sample Pore Vol	0,114	cc
Injection Sample Bulk Vol	4,822	cc
Injection Sample Weight	12,130	g

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Mean Hydraulic Radius	0,005	microns
Swanson's Parameter	0,000	
FZI		





Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

Sample Identification	4	
Sample Depth	19,87	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,009	fraction

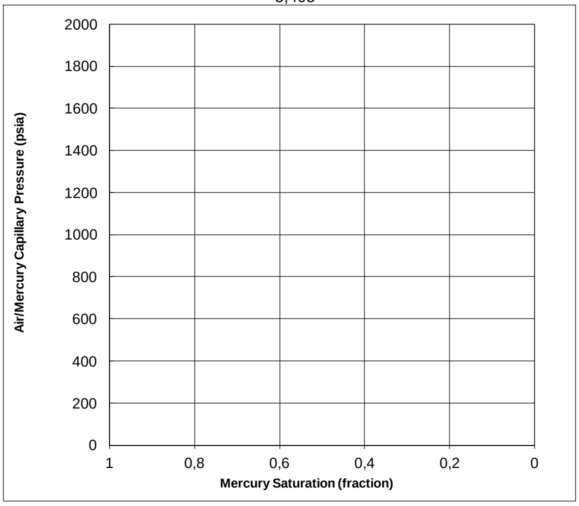
IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

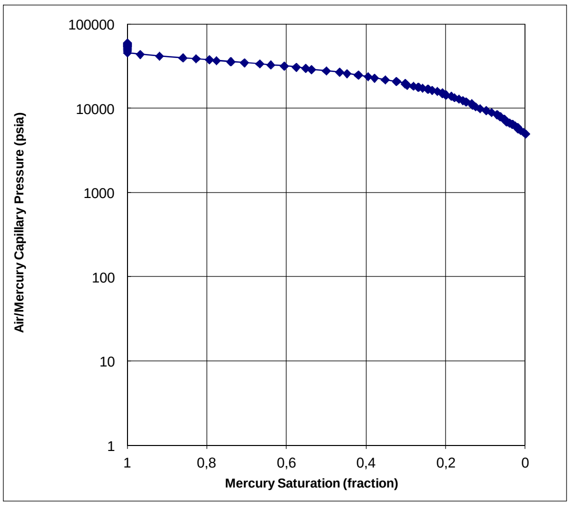
Injection Sample Porosity	0,014	fraction
Injection Sample Pore Vol	0,075	cc
Injection Sample Bulk Vol	5,479	cc
Injection Sample Weight	13,620	g

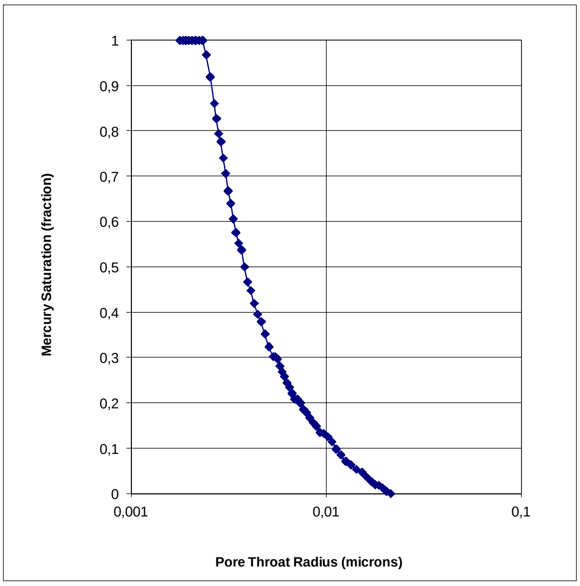
5,40 Grain Vol
2,52 Grain Density

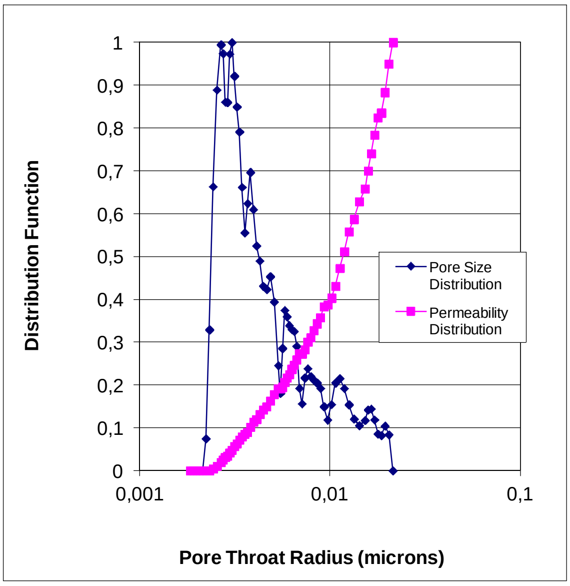
Mean Hydraulic Radius	0,004	microns
Swanson's Parameter	0,000	
FZI		

5,405









Mercury Injection

Client	Geus
Well	Billegrav-2
Reference	Shale Gas

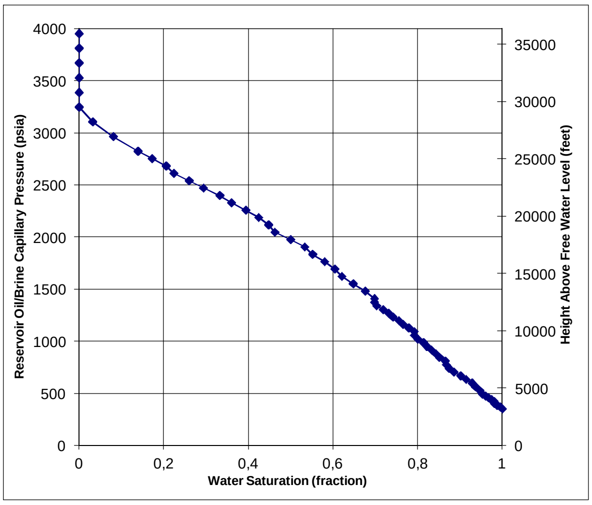
Sample Identification	4	
Sample Depth	19,87	m
Plug Permeability (Air)	n/a	mD
Plug Porosity (He)	0,009	fraction

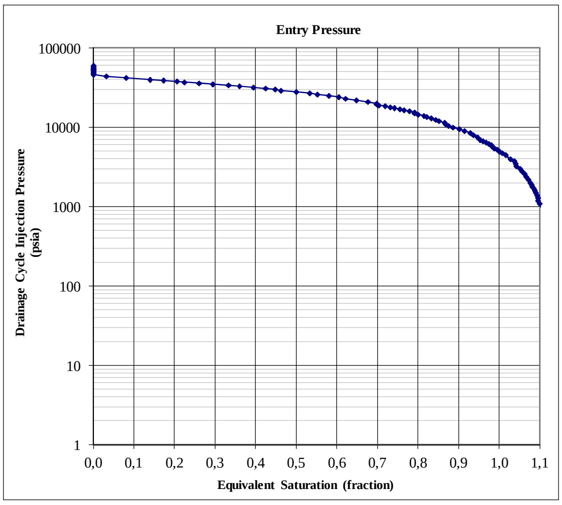
Injection Sample Porosity	0,014	fraction
Injection Sample Pore Vol	0,075	cc
Injection Sample Bulk Vol	5,479	cc
Injection Sample Weight	13,620	g

Brine Density Gradient	0,44	psig/foot
Oil Density Gradient	0,33	psig/foot

IFT x Cos(contact angle)		
	Lab	Res
Air/Brine	72	50
Air/Oil	24	
Oil/Brine	42	26
Air/Hg	368	

Mean Hydraulic Radius	0,004	microns
Swanson's Parameter	0,000	
FZI		





Appendix B: ICP-MS trace element measurements

File: ‘Appendix B ICP-MS elements measurements.xlsx’ in folder Appendix

GEUS 'REE method' - preferential data

Formation	Unit	Depth	Sc	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce
		m	ppm	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Rastrites	F5	5.28	16	0.41	135	82	0.05	31	87	61	78	22	149	74	22	101	13	8	395	37	76
Rastrites	F4	10.70	18	0.46	151	87	0.05	45	72	29	47	24	170	94	22	116	15	9	400	50	108
Rastrites	F4	14.97	17	0.45	145	84	0.04	52	75	55	47	23	163	77	24	113	15	9	390	44	98
Rastrites	F4	19.95	12	0.27	219	58	0.02	18	101	56	61	16	99	65	23	85	9	6	354	28	59
Rastrites	F4	23.18	14	0.34	307	84	0.03	19	84	92	38	18	131	74	23	104	12	8	370	33	67
Rastrites	F4	24.90	18	0.42	279	135	0.03	24	131	96	65	21	153	82	29	142	14	9	364	39	80
Rastrites	F4	29.99	19	0.44	142	137	0.02	15	56	56	47	22	170	71	21	135	15	9	371	40	85
Rastrites	F3	35.10	13	0.32	87	98	0.15	24	50	36	42	16	119	146	25	110	12	6	302	34	83
Rastrites	F3	41.15	11	0.33	84	112	0.14	20	48	36	47	15	104	169	22	120	12	6	282	32	72
Rastrites	F3	42.74	12	0.36	93	107	0.14	23	61	40	53	17	119	159	24	132	13	6	303	33	73
Rastrites	F3	45.00	16	0.41	145	85	0.05	31	83	65	66	23	142	77	23	101	13	8	386	36	75
Rastrites	F2	50.90	14	0.38	105	107	0.03	19	76	50	74	19	135	63	21	107	13	7	347	33	71
Rastrites	F1	56.60	14	0.40	107	104	0.13	16	61	35	48	20	137	112	28	126	14	7	339	39	85
Lindegård	E3	61.37	12	0.32	92	97	0.39	17	63	39	48	16	111	145	32	101	11	6	302	32	70
Lindegård	E1	69.53	17	0.44	115	212	0.27	27	172	17	52	23	142	79	41	0	15	8	361	41	93
Dicellogp.	D3	74.99	18	0.41	207	154	0.05	18	82	83	107	20	141	71	29	125	13	9	370	40	91
Dicellogp.	D3	76.89	14	0.30	199	195	0.05	15	128	75	37	15	110	54	28	92	9	7	314	30	62
Dicellogp.	D3	80.47	12	0.26	299	124	0.06	14	99	109	2268	14	102	55	23	90	9	7	296	24	48
Dicellogp.	D2	86.68	15	0.35	98	112	0.08	16	66	29	61	17	124	89	24	110	12	7	368	34	70
Dicellogp.	D1	93.47	9	0.13	38	31	0.02	5	29	25	30	13	64	55	22	106	18	5	293	32	66
Alum	B4	96.76	13	0.42	1045	69	0.02	19	137	193	42	19	116	53	35	114	14	9	443	36	70
Alum	B3	98.90	14	0.45	1786	80	0.02	22	281	219	477	21	140	96	30	123	15	9	8524	38	69
Alum	B3	101.57	15	0.48	2086	81	0.01	31	394	134	206	22	151	50	41	127	15	9	834	44	88
Alum	B3	102.93	15	0.46	1071	69	0.04	30	185	180	34	25	150	86	61	138	16	9	3288	47	107
Alum	B3	105.90	17	0.46	558	63	0.06	30	111	136	19	24	153	64	46	125	16	10	2297	42	88
Alum	B3	110.98	14	0.45	931	69	0.02	30	243	150	7356	25	145	165	38	120	15	10	9322	41	83
Alum	B2	113.35	16	0.50	300	69	0.02	25	70	175	190	23	174	52	37	130	17	13	864	41	83
Alum	B2	115.75	17	0.52	366	72	0.02	31	84	157	125	25	169	50	43	138	16	12	704	47	99
Alum	B2	116.86	17	0.50	351	72	0.02	33	85	175	100	23	171	43	35	129	16	12	711	41	84
Alum	B2	119.90	18	0.53	432	74	0.02	26	97	135	83	25	201	49	33	145	18	13	680	44	89

Unit	Depth	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
	m	ppm	ppm	ppm	ppm	ppm	ppm	Ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
F5	5.28	8	29	5.45	1.12	4.87	0.75	4.25	0.85	2.37	0.38	2.45	0.38	2.92	0.90	64	10	4
F4	10.70	11	41	6.50	1.12	5.04	0.76	4.35	0.84	2.44	0.37	2.35	0.38	3.25	1.06	34	11	3
F4	14.97	9	35	6.03	1.18	4.96	0.78	4.43	0.88	2.70	0.40	2.62	0.40	3.26	1.03	29	11	4
F4	19.95	6	26	5.06	1.01	4.85	0.73	4.17	0.85	2.45	0.40	2.37	0.37	2.32	0.63	42	7	12
F4	23.18	7	29	5.03	0.95	4.61	0.70	4.15	0.83	2.41	0.38	2.44	0.38	2.88	0.80	47	8	7
F4	24.90	9	35	6.70	1.21	6.27	0.97	5.60	1.12	3.22	0.50	3.20	0.51	3.75	0.96	53	10	9
F4	29.99	9	33	4.99	0.74	4.02	0.68	4.02	0.81	2.52	0.40	2.63	0.43	3.69	1.02	9	11	4
F3	35.10	8	29	5.58	1.17	5.30	0.79	4.48	0.86	2.46	0.36	2.30	0.35	2.84	0.75	21	8	2
F3	41.15	8	30	5.68	1.16	5.22	0.77	4.05	0.77	2.24	0.33	2.14	0.33	3.18	0.77	20	9	3
F3	42.74	8	29	5.38	1.15	4.99	0.77	4.33	0.84	2.41	0.35	2.30	0.35	3.40	0.83	25	9	3
F3	45.00	8	31	5.78	1.12	4.97	0.76	4.34	0.83	2.39	0.36	2.37	0.36	2.80	0.93	63	10	4
F2	50.90	8	29	4.90	0.85	4.24	0.66	3.77	0.72	2.17	0.34	2.14	0.33	2.94	0.90	44	9	4
F1	56.60	9	37	7.05	1.47	6.28	0.92	5.09	0.97	2.78	0.40	2.59	0.41	3.50	0.93	30	10	3
E3	61.37	8	31	6.29	1.49	6.20	0.93	5.27	1.00	2.73	0.42	2.46	0.37	2.66	0.74	11	8	2
E1	69.53	11	45	12.00	2.60	11.42	1.56	8.11	1.43	3.77	0.55	3.40	0.52	3.52	0.97	3	11	2
D3	74.99	9	33	5.53	1.14	5.35	0.82	4.88	0.97	2.84	0.45	2.94	0.46	3.46	0.85	32	10	6
D3	76.89	7	26	5.18	1.03	5.10	0.81	4.52	0.93	2.58	0.40	2.56	0.40	2.63	0.59	39	7	8
D3	80.47	6	23	4.44	0.86	4.30	0.66	3.79	0.77	2.19	0.34	2.09	0.34	2.62	0.53	41	7	5
D2	86.68	7	23	3.92	0.72	3.68	0.63	3.78	0.78	2.41	0.38	2.48	0.38	3.16	0.74	27	7	2
D1	93.47	7	27	5.83	0.84	5.26	0.80	4.50	0.82	2.36	0.34	2.17	0.31	3.79	0.74	34	8	3
B4	96.76	9	32	6.32	1.21	6.26	1.01	6.11	1.25	3.72	0.58	3.88	0.57	3.24	0.94	60	12	52
B3	98.90	8	28	5.08	0.35	4.76	0.81	5.06	1.05	3.36	0.56	3.65	0.56	3.53	1.05	36	12	48
B3	101.57	10	39	7.56	1.42	7.36	1.16	6.68	1.33	3.97	0.61	3.83	0.59	3.65	1.10	31	12	78
B3	102.93	14	59	14.21	2.70	13.74	2.03	11.18	2.10	5.67	0.78	4.77	0.71	3.78	1.14	32	15	90
B3	105.90	10	38	7.30	1.37	7.33	1.21	7.42	1.54	4.48	0.68	4.35	0.66	3.68	1.05	25	12	69
B3	110.98	10	37	7.09	0.79	7.06	1.11	6.63	1.32	3.89	0.61	3.78	0.59	3.34	0.98	23	12	80
B2	113.35	10	36	7.07	1.30	6.68	1.06	6.48	1.29	3.95	0.62	4.13	0.63	3.74	1.11	28	14	26
B2	115.75	12	47	9.77	1.97	9.65	1.49	8.31	1.58	4.41	0.68	4.26	0.63	3.92	1.13	27	14	35
B2	116.86	10	37	7.52	1.39	7.09	1.11	6.50	1.29	3.64	0.57	3.64	0.56	3.67	1.07	31	14	32
B2	119.90	11	40	7.77	1.44	7.01	1.07	6.33	1.26	3.69	0.59	3.77	0.58	4.03	1.15	143	14	34

Elements measured on PerkinElmer Elan 6100DRC ICP-MS with the PerkinElmer's TotalQuant method.

Appendix B

Formation	Unit	Depth	Ag	Al	As	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er	Eu
		m	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Rastrites	F5	5.28	0.01	90021	22	0	371	0.00	0.00	3678	0.00	66	35	84	7	73	3.91	2.13	1.13
Rastrites	F4	10.70	0.00	99669	32	0	358	0.00	0.00	2356	0.00	87	47	87	8	30	3.48	1.94	1.02
Rastrites	F4	14.97	0.00	98129	19	0	337	0.00	0.00	1207	0.00	78	54	80	8	59	3.73	2.18	1.04
Rastrites	F4	19.95	0.00	58474	11	0	319	0.00	0.00	2069	0.00	48	18	58	5	59	3.57	1.95	0.91
Rastrites	F4	23.18	0.00	73636	16	0	322	0.00	0.00	4009	0.00	52	19	84	7	102	3.44	2.01	0.83
Rastrites	F4	24.90	0.00	80299	42	0	320	0.00	0.00	7371	0.00	63	24	126	8	109	4.42	2.60	1.02
Rastrites	F4	29.99	0.00	85659	5	0	328	0.00	0.00	3001	0.00	68	14	128	7	57	3.25	1.94	0.65
Rastrites	F3	35.10	0.00	63078	1	0	270	0.00	0.00	78752	0.00	68	23	98	5	37	3.73	1.92	1.02
Rastrites	F3	41.15	1.03	59391	11	169	262	2.74	0.52	78064	0.19	62	19	112	5	37	3.51	1.91	1.05
Rastrites	F3	42.74	0.39	63506	7	49	277	0.00	0.00	65324	0.00	61	22	99	5	40	3.67	1.91	1.02
Rastrites	F3	45.00	0.00	86414	20	0	352	0.00	0.00	3112	0.00	62	30	78	7	68	3.49	1.96	0.94
Rastrites	F2	50.90	0.00	72544	11	0	323	0.00	0.00	3978	0.00	59	19	102	7	50	3.12	1.81	0.73
Rastrites	F1	56.60	0.00	73443	0	0	318	0.00	0.00	41425	0.00	74	16	99	6	34	4.35	2.29	1.31
Lindegård	E3	61.37	0.00	63808	0	0	296	0.00	0.00	101374	0.00	63	16	101	5	44	4.51	2.48	1.40
Lindegård	E1	69.53	0.00	82602	0	0	344	0.00	0.00	25925	0.00	80	26	202	7	16	7.06	3.15	2.20
Dicellogp.	D3	74.99	0.00	79877	12	20	355	0.00	0.00	7059	0.15	72	19	164	8	98	4.18	2.41	0.97
Dicellogp.	D3	76.89	0.00	55350	18	3	298	0.13	0.00	8638	0.00	49	17	214	6	92	3.99	2.21	0.91
Dicellogp.	D3	80.47	0.00	51793	14	0	274	0.00	0.00	10263	21.14	38	15	133	6	131	3.22	1.78	0.75
Dicellogp.	D2	86.68	0.00	61551	7	0	338	0.00	0.00	17324	0.02	53	16	123	6	33	3.31	1.89	0.66
Dicellogp.	D1	93.47	0.00	40741	14	0	278	0.00	0.00	5492	0.00	51	5	32	4	29	3.75	1.82	0.73
Alum	B4	96.76	2.69	65737	83	32	431	4.50	0.05	5297	1.02	57	22	76	8	237	5.26	3.06	1.23
Alum	B3	98.90	1.91	74012	81	23	7857	4.02	0.00	7628	21.11	53	24	86	8	256	4.18	2.59	1.81
Alum	B3	101.57	1.22	75751	78	28	798	7.00	0.00	4082	7.76	66	33	89	8	154	5.35	3.08	1.24
Alum	B3	102.93	1.47	80030	109	110	3227	8.62	0.00	12695	2.45	80	32	75	8	211	8.72	4.52	2.61
Alum	B3	105.90	0.60	79462	67	80	2262	5.79	0.00	19459	0.99	66	32	68	8	161	6.01	3.32	1.41
Alum	B3	110.98	0.55	74843	72	72	10280	4.82	0.00	6333	225.07	62	32	76	9	176	5.20	2.99	2.27
Alum	B2	113.35	0.09	82405	66	58	841	2.42	0.00	1568	2.45	61	26	77	10	207	5.16	3.08	1.08
Alum	B2	115.75	0.20	83644	56	48	673	1.50	0.00	2139	1.37	72	32	77	10	181	6.51	3.34	1.54
Alum	B2	116.86	0.18	78550	74	34	625	0.64	0.00	1556	0.92	61	35	76	10	195	5.17	2.78	1.21
Alum	B2	119.90	0.13	82063	71	7	606	0.19	0.00	1077	0.61	66	26	78	11	153	4.97	2.61	1.17

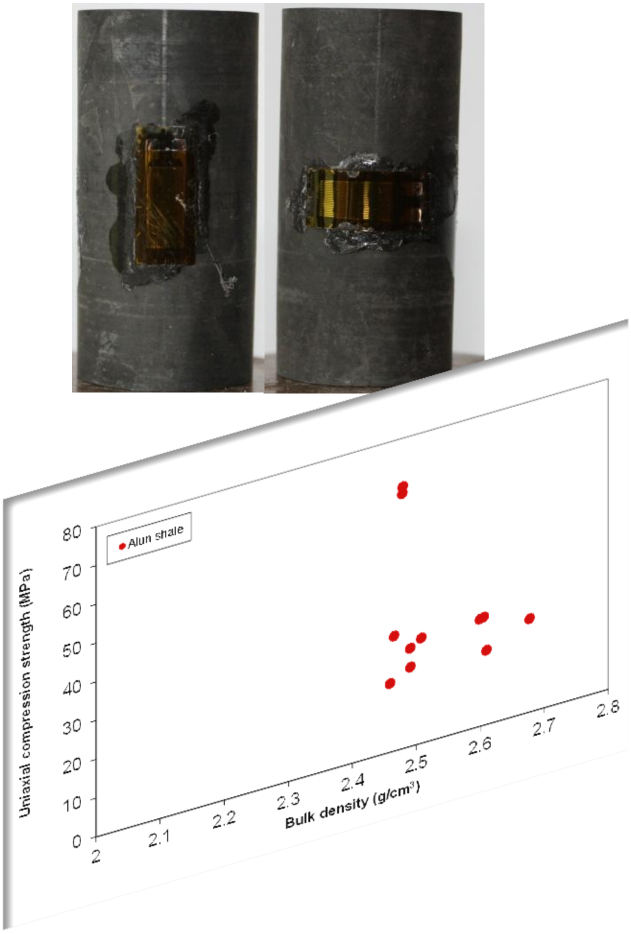
Unit	Depth	Fe	Ga	Gd	Hf	Ho	K	La	Li	Lu	Mg	Mn	Mo	Na	Nb	Nd	Ni	P	Pb
	m	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
F5	5.28	47783	23.11	5.01	2.12	0.77	27810	30	54	0.33	13212	532	9	3393	13	28	91	296	63
F4	10.70	52582	23.37	4.45	2.36	0.64	29573	39	63	0.29	15287	526	0	3470	15	36	71	301	30
F4	14.97	54425	21.70	4.54	2.44	0.75	27211	34	68	0.31	15987	443	3	3077	14	31	73	279	26
F4	19.95	28471	14.01	4.67	1.55	0.67	18851	22	22	0.29	7983	203	35	2680	8	23	96	353	40
F4	23.18	32940	16.72	4.44	2.12	0.64	23782	26	27	0.28	10294	260	14	3568	11	25	82	271	44
F4	24.90	45499	18.28	5.98	2.76	0.83	27263	29	43	0.37	13694	330	13	4185	13	30	123	308	44
F4	29.99	29201	19.65	3.68	2.52	0.62	28366	30	44	0.30	16599	210	0	4095	14	28	49	277	8
F3	35.10	27455	14.74	5.14	2.31	0.71	21484	27	29	0.28	11815	1537	0	3064	11	26	46	252	20
F3	41.15	24763	14.72	4.91	2.51	0.75	21305	25	28	0.32	11736	1410	2	3439	11	27	42	335	20
F3	42.74	26930	15.53	4.54	2.62	0.66	22476	25	31	0.31	13901	1291	1	3621	12	25	54	288	22
F3	45.00	45131	20.61	4.44	2.00	0.65	27505	29	52	0.31	13136	467	6	3384	12	27	77	239	56
F2	50.90	33197	17.14	3.93	2.17	0.62	26132	27	39	0.27	13330	255	6	3750	12	26	72	201	40
F1	56.60	32398	17.99	5.95	2.53	0.78	26900	31	44	0.33	14032	1295	0	3217	13	32	59	263	27
F1	61.37	29455	16.11	6.16	2.21	0.85	22699	27	34	0.31	12543	4125	0	2633	11	29	61	295	10
E1	69.53	62786	20.97	10.84	2.71	1.21	28138	34	51	0.43	26462	2626	0	2181	14	41	151	926	1
D3	74.99	33031	20.48	5.20	2.59	0.70	31869	31	41	0.34	14117	496	3	3946	13	30	93	636	36
D3	76.89	24769	15.36	4.82	1.87	0.69	23214	23	27	0.29	9177	510	7	2902	9	24	144	497	43
D3	80.47	30310	15.26	4.60	1.72	0.59	20465	18	29	0.25	9688	601	28	2817	9	20	112	331	46
D2	86.68	33446	17.21	3.71	2.33	0.60	25887	26	42	0.27	15265	881	0	3064	12	21	70	278	28
D1	93.47	17390	13.49	4.83	2.70	0.66	15994	25	21	0.23	7470	210	3	1495	18	24	30	250	35
B4	96.76	38021	20.47	6.00	2.23	1.13	29364	30	35	0.59	10663	206	109	2708	14	29	158	906	65
B3	98.90	43402	22.21	4.55	2.43	0.82	34769	29	30	0.46	9918	256	106	1932	15	25	296	410	36
B3	101.57	53822	21.68	6.70	2.36	1.00	35937	32	26	0.45	7881	148	134	1322	14	33	400	910	29
B3	102.93	53531	25.60	12.20	2.58	1.56	37810	35	24	0.49	7345	409	260	1042	15	50	196	1.646	28
B3	105.90	45960	23.58	6.65	2.45	1.12	40129	31	22	0.50	6908	676	93	1429	15	31	114	835	22
B3	110.98	57275	25.70	6.20	2.34	0.96	36096	31	21	0.41	6895	237	172	1498	14	31	256	644	19
B2	113.35	59888	23.13	5.83	2.56	0.95	42912	30	27	0.44	8898	217	46	2376	15	30	69	496	27
B2	115.75	59457	25.21	8.57	2.50	1.10	40495	34	34	0.43	10280	226	62	2347	15	39	89	702	25
B2	116.86	74186	23.57	6.18	2.53	0.91	39678	30	30	0.38	9535	211	74	1906	15	31	90	461	27
B2	119.90	64267	23.38	5.90	2.70	0.90	46242	32	34	0.40	10314	187	99	2334	16	32	86	413	139

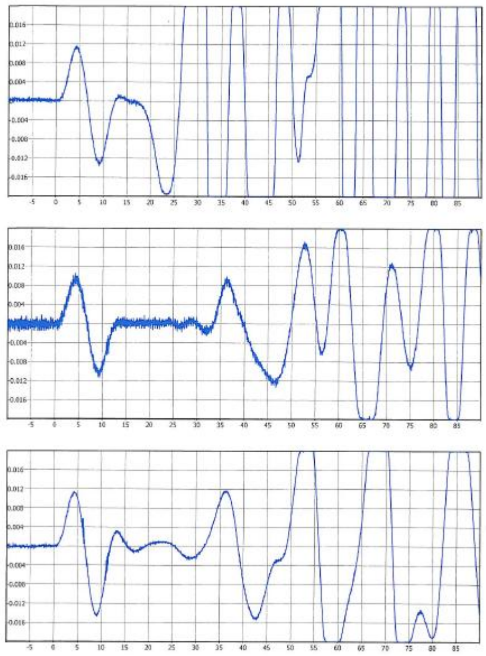
Unit	Depth	Pr	Rb	Sb	Sc	Se	Sm	Sn	Sr	Ta	Tb	Te	Th	Ti	Tl	Tm	U	V	Y	Yb	Zn	Zr
	m	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
F5	5.28	7.05	142	2.3	12.6	0	5	3	75	0.85	0.74	0.00	9.95	3944	0.93	0.35	3	143	17	2.05	97	112
F4	10.70	9.03	162	1.4	13.4	0	6	3	88	0.95	0.63	0.00	9.97	3995	0.15	0.31	2	156	15	1.88	50	118
F4	14.97	7.85	153	2.9	12.0	0	5	3	71	0.98	0.64	0.00	9.71	3882	0.21	0.31	3	143	16	2.20	49	116
F4	19.95	5.57	90	2.5	8.2	0	5	2	61	0.55	0.64	0.00	6.42	2502	0.87	0.27	10	224	16	1.96	65	90
F4	23.18	5.91	120	2.9	10.0	0	4	2	70	0.69	0.59	0.00	7.61	3076	0.21	0.28	6	309	15	1.93	38	107
F4	24.90	7.14	142	3.1	12.3	0	6	3	74	0.84	0.83	0.00	9.31	3744	0.64	0.37	8	271	19	2.69	73	138
F4	29.99	7.35	144	0.7	12.8	0	4	3	64	0.91	0.53	0.00	9.83	3738	0.00	0.28	3	133	14	2.14	46	131
F3	35.10	6.25	114	0.6	9.7	0	5	2	136	0.72	0.69	0.00	7.70	2878	0.00	0.26	2	89	17	1.81	42	105
F3	41.15	6.56	102	0.6	9.3	1	5	2	156	0.69	0.75	0.26	8.70	3052	0.99	0.30	2	85	15	1.82	60	123
F3	42.74	6.42	118	0.7	9.6	0	5	2	144	0.75	0.65	0.00	7.95	3267	0.10	0.29	2	88	16	1.92	60	132
F3	45.00	6.75	141	2.1	11.7	0	5	3	67	0.84	0.61	0.00	8.38	3599	0.68	0.28	3	140	15	1.95	71	101
F2	50.90	6.34	130	0.8	10.4	0	4	3	55	0.82	0.57	0.00	7.73	3482	0.00	0.26	3	104	14	1.88	82	105
F1	56.60	7.89	134	0.4	11.2	0	6	3	103	0.87	0.80	0.00	8.99	3695	0.00	0.33	3	109	19	2.29	49	127
E3	61.37	6.92	111	0.7	10.4	0	6	2	134	0.74	0.85	0.00	7.44	3242	0.00	0.33	1	98	22	2.25	54	109
E1	69.53	8.87	143	0.2	13.7	0	11	3	74	0.93	1.38	0.00	9.59	4045	0.00	0.41	1	114	28	2.95	57	137
D3	74.99	7.24	158	1.7	14.7	0	5	3	68	0.96	0.65	0.00	7.75	3762	0.49	0.33	6	220	20	2.46	165	129
D3	76.89	5.61	117	1.9	11.4	1	5	2	51	0.64	0.64	0.00	5.45	2718	0.65	0.28	7	213	19	2.15	55	99
D3	80.47	4.57	108	2.3	9.9	1	4	2	68	0.63	0.53	0.00	5.33	2429	1.99	0.23	5	315	15	1.88	3375	96
D2	86.68	5.44	130	0.5	12.6	0	3	2	82	0.81	0.50	0.00	5.96	3142	0.40	0.28	2	106	16	1.97	89	116
D1	93.47	5.72	70	1.3	7.2	0	5	3	52	0.82	0.65	0.00	6.80	1249	0.34	0.23	3	41	15	1.71	44	115
B4	96.76	7.02	126	6.5	11.2	6	5	3	68	0.97	0.95	0.00	10.81	3854	2.12	0.59	52	1139	25	3.24	66	125
B3	98.90	6.02	137	5.9	11.5	5	5	3	89	1.07	0.65	0.22	9.62	4037	4.76	0.41	46	1876	20	2.79	757	127
B3	101.57	7.84	140	5.7	11.7	11	7	3	45	1.05	0.92	0.00	9.61	4157	8.71	0.43	71	2200	26	3.06	309	127
B3	102.93	10.40	142	5.0	12.3	8	12	3	82	1.16	1.48	0.41	11.35	4169	5.42	0.52	77	1150	41	3.64	59	142
B3	105.90	7.83	142	2.6	13.4	3	6	3	59	1.06	0.94	0.00	9.19	4265	2.98	0.47	60	594	30	3.52	31	129
B3	110.98	7.32	141	4.2	11.9	7	6	3	157	1.03	0.85	0.16	8.63	4211	7.33	0.40	68	992	26	3.08	10975	124
B2	113.35	7.05	158	2.4	13.6	2	6	4	48	1.16	0.77	0.00	10.08	4546	2.15	0.42	22	318	24	3.33	289	132
B2	115.75	8.73	155	2.6	13.5	2	8	4	45	1.16	1.14	0.00	9.98	4650	2.60	0.43	29	376	28	3.06	189	136
B2	116.86	7.10	157	2.8	12.8	2	6	4	41	1.07	0.79	0.00	9.69	4287	3.94	0.35	27	354	23	2.83	145	130
B2	119.90	7.75	175	2.7	14.3	4	6	4	44	1.16	0.85	0.00	10.19	4821	5.96	0.37	28	459	21	2.66	116	141

Appendix C: Geotechnical report

Alun shale
Laboratory testing

GEO project no 34780
Report 1, 2011-06-10





GEO
Maglebjergvej 1
DK-2800 Kgs. Lyngby
Tel: +45 4588 4444
Fax: +45 4588 1240
geo@geo.dk
www.geo.dk
CVR-no: 59781812

Prepared for
GEUS
Att: Niels Hemmingsen Schovsbo
Øster Voldgade 10
1350 København K

Prepared by Frederik Ditlevsen, M.Sc.
+45 4520 4196, fpd@geo.dk

Checked by Niels Trads, Ph.D.
+45 4520 4289, nit@geo.dk

Contents

Enclosures

1 Overview of plug samples
2 Unconfined compression test results, Overview
3 Unconfined compression test, Lab. No. 4A
4 Unconfined compression test, Lab. No. 4B
5 Unconfined compression test, Lab. No. 9A
6 Unconfined compression test, Lab. No. 9B
7 Unconfined compression test, Lab. No. 17A
8 Unconfined compression test, Lab. No. 17B
9 Unconfined compression test, Lab. No. 17C
10 Unconfined compression test, Lab. No. 22A
11 Unconfined compression test, Lab. No. 22C
12 Unconfined compression test, Lab. No. 28A
13 Unconfined compression test, Lab. No. 28B
14 Brazil test results, Overview

1 Objective

The objective of the project is to determine the strength and deformation properties through a number of unconfined compression tests and Brazil tests. Further, to measure the acoustic velocity in three directions relative to the bedding plane.

2 Core handling and preparation

30 plug samples of Alun shale were delivered by GEUS. The samples represent the four formations, Rastrites, Lindegaard, Dicellograptus and Alum. 18 samples were preserved in foil, 3 were preserved in water and 9 were not preserved. The dimensions of the samples were approximately 55mm in diameter and lengths varying between 50-140mm. An overview of the samples is shown in Enclosure 1.

The plug samples were prepared for three different tests; unconfined compression test, Brazil test and acoustic measurements. The specimen preparation varied for the three test types. In all cases the plug samples were installed in gypsum before preparation and cored using tap water as coolant.

In agreement with GEUS, the samples were selected for individual testing based on sample dimensions and number of individual tests requested in each formation. Table 1 shows the number of individual tests in each formation. A complete overview of the prepared specimens is found in Enclosure 1.

Formation	Acoustic velocity measurements		Unconfined compression test		Brazil tests	
	Plug samples	Test specimens	Plug samples	Test specimens	Plug samples	Test specimens
Rastrites	8	18	4	4	2	3
Lindegård	1	3	0	0	0	0
Dicellograptus	2	7	1	3	1	2
Alum	6	14	2	4	3	5
Total	17	42	7	11	6	10

Table 1 Overview of plug samples and test specimens selected for individual test in the four formations.

Specimens prepared for unconfined compression tests are cored in vertical direction perpendicular to a horizontal bedding plane, cf. Figure 1. Two parallel specimens could be cored from each selected plug samples. The dimensions of the prepared specimens are approximately 25mm in diameter and 50mm in length.

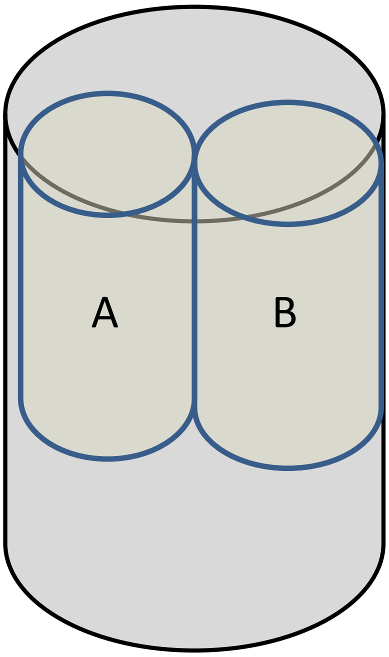


Figure 1 Sketch of coring orientation and placement of specimens for unconfined compression tests in the plug samples.

Specimens prepared for acoustic measurements are cored in three directions as specified in Figure 2 (vertical, horizontal and 45° angle). Hence, three specimens are prepared from each selected plug sample. After coring one direction, the sample is re-installed in gypsum prior to coring the second direction and again re-installed in gypsum prior to the third coring attempt. The prepared specimens are approximate 25mm in diameter and as long as possible.

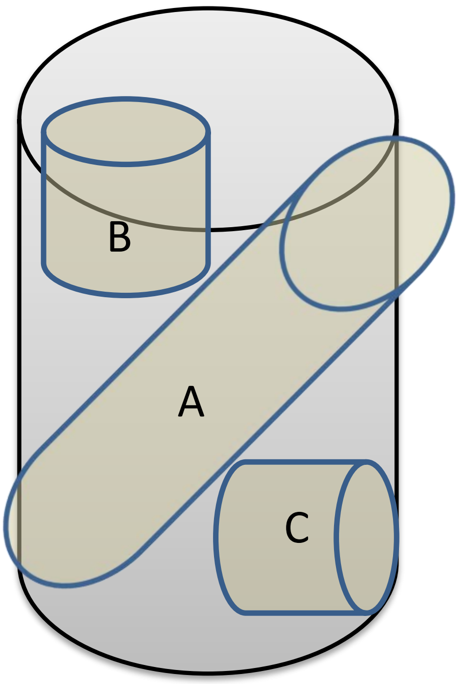


Figure 2 Sketch of coring orientation for specimens prepared for acoustic measurements (A: 45°, B: vertical, C: horizontal).

Table 2 shows the successful prepared specimens for acoustic measurements. 42 specimens were prepared from 51 attempts.

Sample No	Formation	top	base	preserved in foil	Preserved in water	not preserved	GEO suggested test types	Coring orientation			Coring attempts	No. Of tests
1	**Rastrites**	5.18	5.28	1			Acoustic	Vert.	~~Hor.~~	45 deg.	3	2
3	**Rastrites**	14.9	14.97	1			Acoustic	~~Vert.~~	~~Hor.~~	~~45 deg.~~	3	0
6	**Rastrites**	24.8	24.9	1			Acoustic	Vert.	Hor.	45 deg.	3	3
8	**Rastrites**	35	35.1	1			Acoustic	Vert.	Hor.	45 deg.	3	3
11	**Rastrites**	44.9	45	1			Acoustic	Vert.	Hor.	45 deg.	3	3
12	**Rastrites**	50.82	50.9			1	Acoustic	Vert.	Hor.	45 deg.	3	3
13	**Rastrites**	56.52	56.6			1	Acoustic	Vert.	~~Hor.~~	~~45 deg.~~	3	1
14	**Rastrites**	61.3	61.37	1			Acoustic	Vert.	Hor.	45 deg.	3	3
15	**Lindegård**	69.39	69.53	1			Acoustic	Vert.	Hor.	45 deg.	3	3
16	**Dicellogp.**	74.9	74.99	1			Acoustic	Vert.	Hor.	2 x 45 deg.	3	4
18	**Dicellogp.**	80.4	80.47	1			Acoustic	Vert.	Hor.	45 deg.	3	3
20	**Alum**	93.4	93.47			1	Acoustic	~~Vert.~~	~~Hor.~~	45 deg.	3	1
23	**Alum**	101.5	101.57		1		Acoustic	Vert.	Hor.	45 deg.	3	3
25	**Alum**	105.8	105.9	1			Acoustic	Vert.	~~Hor.~~	45 deg.	3	2
26	**Alum**	110.9	110.98	1			Acoustic	Vert.	Hor.	45 deg.	3	3
29	**Alum**	116.775	116.86		1		Acoustic	Vert.	Hor.	45 deg.	3	3
30	**Alum**	119.8	119.9	1			Acoustic	~~Vert.~~	Hor.	45 deg.	3	2
Total								**14**	**12**	**16**		**42**

Table 2 Overview of prepared specimens for acoustic measurements.

Specimens prepared for Brazil tests are maintained in the original diameter (55 mm) and cut into lengths of 27mm.

Due to the layering of the Alun shale and the condition of the plug samples, the prepared specimens were very fragile and had a tendency to split into smaller pieces.

3 Test desciptions

3.1 Unconfined compression test

Unconfined compression tests were carried out in GEO's Wykeham Farrance load frame. All tests included an unloading/reloading phase and two acoustic measurements at selected stress levels.

Axial deformation of the entire specimen was measured using two LVDT's. Local axial and radial deformations are monitored by two strain gauges, situated at the centre of the specimen. The tests are carried out according to ISRM, Suggested Methods, part 1 and part 2, pp. 153 (2007).

The uniaxial compression strength, Young's modulus of elasticity and Poisson's ratio are determined from each test.

The acoustic measurements are not interpreted but delivered as data-files in the enclosed CD.

3.2 Acoustic measurements

Acoustic measurements are performed on specimens prepared in three directions (45º angles, vertical and horizontal). Compressional and shear wave travelling times (τ_p, τ_{s1} and τ_{s2}) are measured at 1 MPa and 3 MPa axial stress level, when possible. In many cases, the acoustic measurement at 3 MPa could not be performed on specimens oriented 45º because the specimen would fail.

The acoustic waves are generated by applying a voltage to a piezoelectric crystal, which then creates either compression or shear waves through the specimen, depending on the type of crystal used. The mechanical displacement generated by the crystal is recorded at the other end of the specimen, where another piezoelectric crystal creates a voltage due to the experience of deformation. An oscilloscope measures the voltage of the signal recorded. The recordings by the oscilloscope are manually controlled enabling an optimization of the measurement and hence minimize the uncertainty in the interpretation. Two orthogonal shear waves and one compression wave are generated and recorded when acoustic measurements are performed. The waves are generated with a frequency of 100 kHz.

The measured travel time must be corrected for the system lag-time, which is the time it takes for creating the wave and recording the wave. The lag-time is dependent upon the set-up used in each test. Two set-ups are used in this project, because of the need to use extra steel plug when testing specimens shorter than 2cm, cf. Table 3-1.

Table 3-1 System lag-times in acoustic measurements.

System	System lag-time		
	τ_p (µsec)	τ_{s1} (µsec)	τ_{s2} (µsec)
A	3.6	5.7	5.7
B (w. steel plug)	9.3	17.1	16.8

In agreement with GEUS, the measurements are not interpreted but delivered as data-files in the enclosed CD.

3.3 Brazil test

Brazilian tests were carried out in GEO's Wykeham Farrance load frame. Vertical deformation measurements were obtained using one LVDT (Linear Voltage Displacement Transducer). The tests were carried out according to ISRM, Suggested Methods, part 1, pp. 119 (1981).

From the Brazil tests the indirect tensile strength (σ_t) is determined.

4 Results

4.1 Unconfined compression tests

The results from the unconfined compression tests are shown in Enclosure 2. The individual stress-strain curves and interpretations of Young's modulus of elasticity and Poisson's ratio are shown in Enclosure 3 – 13.

Figure 3 shows the determined uniaxial compressive strengths. The majority of the specimens have strengths from 17-28 MPa. However, the shallowest two specimens show higher strengths, 65-68 MPa.

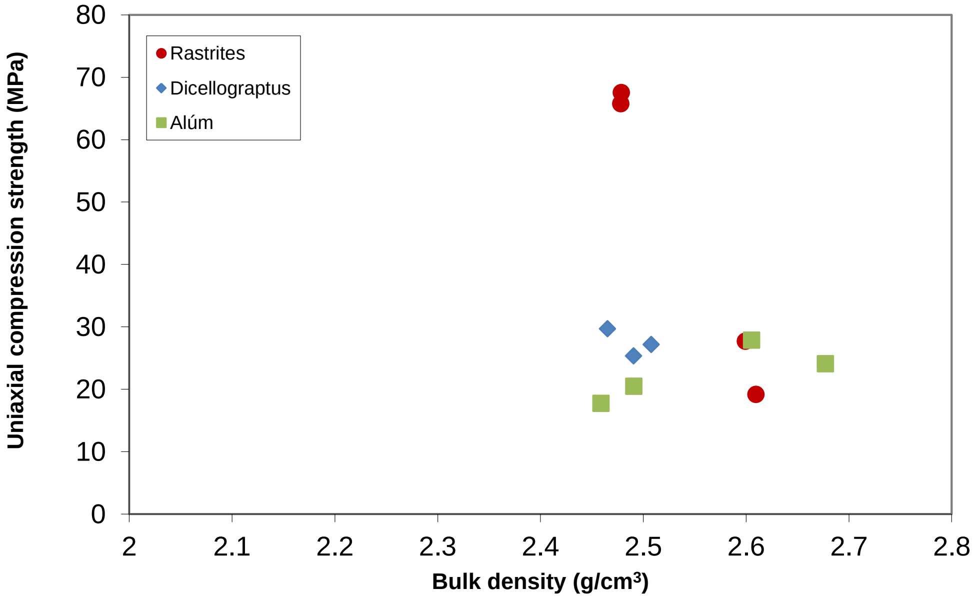


Figure 3 Results of unconfined compressive strength from unconfined compression tests.

The same variation is seen for Young's modulus of elasticity, where the same two specimens show higher moduli, cf. Figure 4.

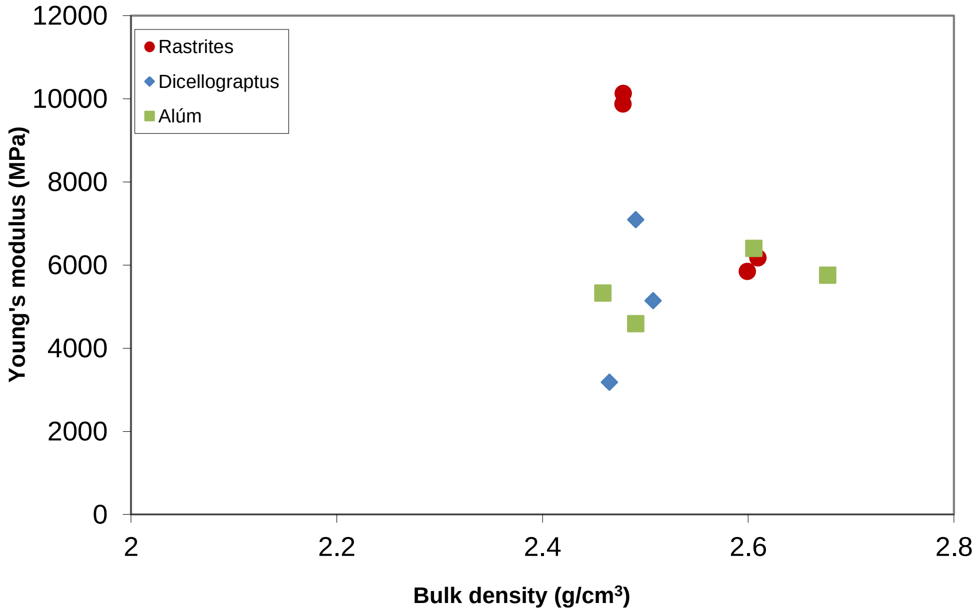


Figure 4 Results of Young's Modulus of elasticity from unconfined compression tests.

Poisson's ratio (Figure 5) tends to scatter and be less dependent on variations in bulk density. The results determined show values between 0.06 – 0.29, which are considered a relatively large interval.

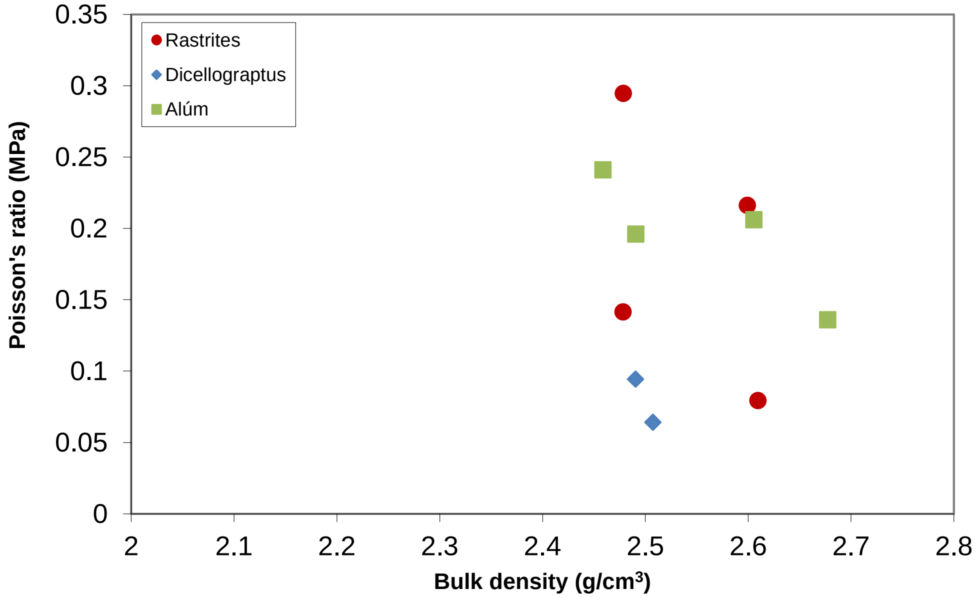


Figure 5 Results of Poisson's ratio from unconfined compression tests.

4.2 Brazil tests

The results from the Brazil tests are shown in Enclosure 14 and plotted in Figure 6.

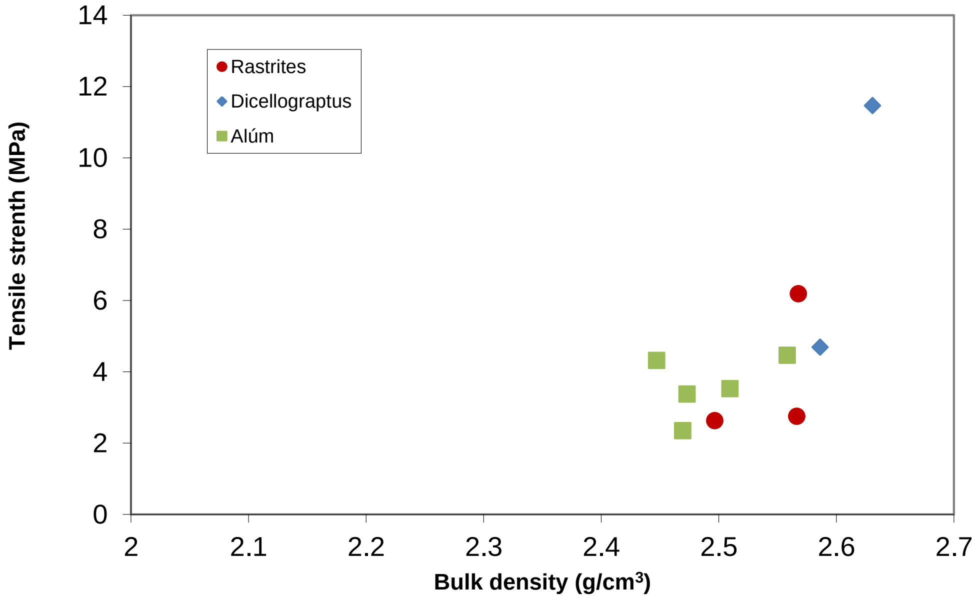


Figure 6 Results of tensile strength from Brazil tests.

The results show a slight increase in tensile strength with increasing bulk density. One test showed a much higher tensile strength. This specimen also had the lowest moisture content and highest bulk density. However, these two parameters cannot alone explain the difference in tensile strength to the other tests.

Enclosure 1

Job:	34780 Alun Shale																
Well:	Billegrav-2																
Sample No	Formation	GEO suggested test types	No. Of tests	Lab. No.	Cored orientation	L1	L2	L3	L4	Av. Length	D1	D2	D3	D4	D5	D6	Av. Diameter
1	Rastrites	Acoustic	2	1A	45°	16.99	16.94	16.97		16.97							
	Rastrites	Acoustic		1B	Vertical	17.41	17.21	17.11		17.24							
2	Rastrites	UCS	0														
3	Rastrites	Acoustic	0														
4	Rastrites	UCS	2	4A	Vertical	50.02	50.04	50.11	50.04	50.05	24.78	24.73	24.75	24.75	24.83	24.78	24.77
	Rastrites	UCS		4B	Vertical	39.51	39.54	39.58	39.47	39.53	24.83	24.78	24.78	24.71	24.85	24.32	24.71
5	Rastrites	Brazil	1							0.00							
6	Rastrites	Acoustic	3	6A	45°	50.2	50.13	50.22		50.18							
	Rastrites	Acoustic		6B	Vertical	13.53	13.03	13.47		13.34							
	Rastrites	Acoustic		6C	Horizontal	30.25	30.25	30.25		30.25							
7	Rastrites	UCS	0														
8	Rastrites	Acoustic	3	8A	45°	15.31	15.24	15.05		15.20							
	Rastrites	Acoustic		8B	Vertical	28.79	28.81	28.79		28.80							
	Rastrites	Acoustic		8C	Horizontal	20.48	20.4	20.46		20.45							
9	Rastrites	UCS	2	9A	Vertical	45.92	45.82	45.87	45.81	45.86	24.69	24.66	24.7	24.65	24.73	24.68	24.69
	Rastrites	UCS		9B	Vertical	42.22	42.16	42.27	42.13	42.20	24.61	24.61	24.64	24.62	24.61	24.61	24.62
10	Rastrites	Brazil	2	10A						0.00							
	Rastrites	Brazil		10B						0.00							
11	Rastrites	Acoustic	3	11A	45°	53.32	53.32	53.32		53.32							
	Rastrites	Acoustic		11B	Vertical	38.76	38.57	38.79		38.71							
	Rastrites	Acoustic		11C	Horizontal	12.36	12.39	12.38		12.38	Acoustic meas. Not performed						
	Rastrites	Acoustic		11D	Horizontal	15.92	15.79	15.81		15.84							
12	Rastrites	Acoustic	3	12A	45°	14.4	14.45	14.39		14.41							
	Rastrites	Acoustic		12B	Vertical	17.89	17.99	17.88		17.92							
	Rastrites	Acoustic		12C	Horizontal					0.00							
13	Rastrites	Acoustic	1	13B	Vertical					0.00							
14	Rastrites	Acoustic	3	14A	45°	44.81	44.8	44.83		44.81							
	Rastrites	Acoustic		14B	Vertical	15.43	15.41	15.47		15.44							
	Rastrites	Acoustic		14C	Horizontal	13.97	14.08	13.72		13.92							
15	Lindegård	Acoustic	3	15A	45°	38.63	38.84	38.63		38.70							
	Lindegård	Acoustic		15B	Vertical	29.26	29.3	29.27		29.28							
	Lindegård	Acoustic		15C	Horizontal	27.95	27.99	28.01		27.98							
16	Dicellogp.	Acoustic	3	16A	45°	26.26	25.76	26.06		26.03							
	Dicellogp.	Acoustic		16B	45°	15.7	15.7	15.59		15.66							
	Dicellogp.	Acoustic		16C	Vertical	15.77	15.67	15.44		15.63							
	Dicellogp.	Acoustic		16D	Horizontal	29.14	29.21	29.24		29.20							
17	Dicellogp.	UCS	3	17A	Vertical	30.7	30.91	30.89	30.7	30.80	24.61	24.65	24.54	24.63	24.6	24.64	24.61
	Dicellogp.	UCS		17B	Vertical	38.53	38.31	38.2	38.24	38.32	24.72	24.74	24.69	24.67	24.7	24.72	24.71
	Dicellogp.	UCS		17C	Vertical	30.1	29.87	30.05	29.78	29.95	24.81	24.69	24.68	24.7	24.58	24.66	24.69
18	Dicellogp.	Acoustic	3	18A	45°	38.35	38.32	38.34		38.34							
	Dicellogp.	Acoustic		18B	Vertical	29.45	29.8	29.52		29.59							
	Dicellogp.	Acoustic		18C	Horizontal	12.97	13.07	12.87		12.97							
19	Dicellogp.	Brazil	2	19A						0.00							
	Dicellogp.	Brazil		19B						0.00							
20	Alum	Acoustic	1	20A	45°	47.75	47.83	47.7		47.76							
	Alum	Acoustic		20C	Horizontal	Acoustic meas. Not possible - not parallel ends											
21	Alum	Brazil	2							0.00							
	Alum	Brazil								0.00							
22	Alum	UCS	2	22A	Vertical	34.84	34.89	34.87	34.85	34.86	24.7	24.89	24.68	24.72	24.7	24.75	24.74
	Alum	UCS		22B													
	Alum	UCS		22C	Vertical	46.46	46.41	46.41	46.41	46.42	24.56	24.56	24.63	24.6	24.63	24.6	24.60
23	Alum	Acoustic	3	23A	45°	41.12	40.96	40.9		40.99							
	Alum	Acoustic		23B	Vertical	14.4	14.24	14.41		14.35							
	Alum	Acoustic		23C	Horizontal	10.76	10.95	10.16		10.62							
24	Alum	Brazil	2	24A						0.00							
	Alum	Brazil		24B						0.00							
25	Alum	Acoustic	2	25A	45°	31.74	31.79	31.79		31.77							
	Alum	Acoustic		25B	Vertical	18.9	19.1	19.12		19.04							
26	Alum	Acoustic	3	26A	45°	17.14	17.1	16.78		17.01							
	Alum	Acoustic		26B	Vertical	13.87	14.47	14.57		14.30							
	Alum	Acoustic		26C	Horizontal	19.11	19.14	19.06		19.10							
27	Alum	Brazil	1	27						0.00							
28	Alum	UCS	2	28A	Vertical	40.25	40.22	40.27	40.26	40.25	24.57	24.15	24.64	23.44	24.58	22.57	23.99
	Alum	UCS		28B	Vertical	49.97	49.92	49.98	49.97	49.96	24.65	24.68	24.62	24.69	24.58	24.64	24.64
29	Alum	Acoustic	3	29A	45°	49.79	49.74	49.74		49.76							
	Alum	Acoustic		29B	Vertical	17.95	17.99	18.01		17.98							
	Alum	Acoustic		29C	Horizontal	26.27	26.16	26.51		26.31							
30	Alum	Acoustic	2	30A	45°	37.21	37.25	37.17		37.21							
	Alum	Acoustic		30C	Horizontal	29.16	29.13	29.17		29.15							

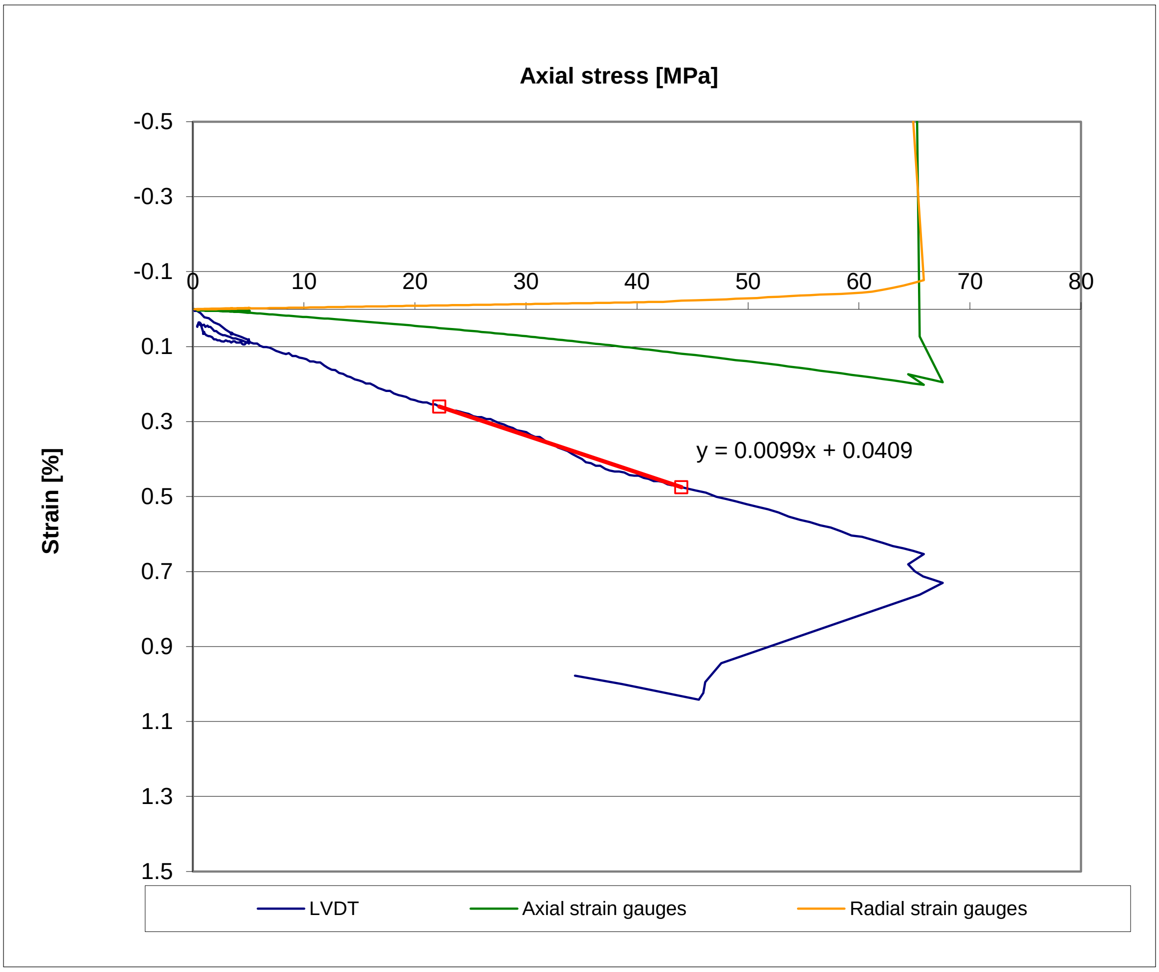
Unconfined compression strength test results

Well	Lab no.	Depth	Geology	Induration	Strain rate	Specimen dimensions: Diameter	Height	Volume	ρ_{bulk}	Moisture content	σ_c	*E*	ν	Test duration
		m			mm/min	cm	cm	cm^3	g/cm^3	%	MPa	MPa		hh:mm:ss
Billegrav-2	4A	19.87	Rastrites		0.05-0.1	2.48	5.01	24.12	2.48	3.2	67.5	10129	0.29	00:28:00
Billegrav-2	4B	19.87	Rastrites		0.05-0.1	2.47	3.95	18.96	2.48	2.8	65.7	9874	0.14	00:21:25
Billegrav-2	9A	41.02	Rastrites		0.05-0.1	2.47	4.59	21.96	2.61	2.0	19.2	6170	0.08	00:19:05
Billegrav-2	9B	41.20	Rastrites		0.05-0.1	2.46	4.22	20.09	2.60	1.9	27.7	5847	0.22	00:18:50
Billegrav-2	17A	76.82	Dicellograptus		0.05-0.1	2.46	3.08	14.65	2.51	2.8	27.1	5144	0.06	00:19:15
Billegrav-2	17B	76.85	Dicellograptus		0.05-0.1	2.47	3.83	18.38	2.49	2.9	25.4	7090	0.09	00:18:05
Billegrav-2	17C	76.85	Dicellograptus		0.05-0.1	2.47	3.00	14.34	2.47	2.8	29.7	3183	---	00:22:40
Billegrav-2	22A	98.86	Alúm		0.05-0.1	2.47	3.49	16.76	2.49	2.7	20.5	4588	0.20	00:18:20
Billegrav-2	22C	98.81	Alúm		0.05-0.1	2.46	4.64	22.06	2.46	2.6	17.7	5324	0.24	00:18:55
Billegrav-2	28A	115.67	Alúm		0.05-0.1	2.40	4.03	18.19	2.68	2.5	24.1	5757	0.14	00:19:55
Billegrav-2	28B	115.67	Alúm		0.05-0.1	2.46	5.00	23.82	2.61	2.4	27.9	6402	0.21	00:20:10

Coring machine: Shibuya Ultimate R Evolution
Testing Machine: Wykeham Farrance 250 kN stepless load frame

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp 153 (2007)

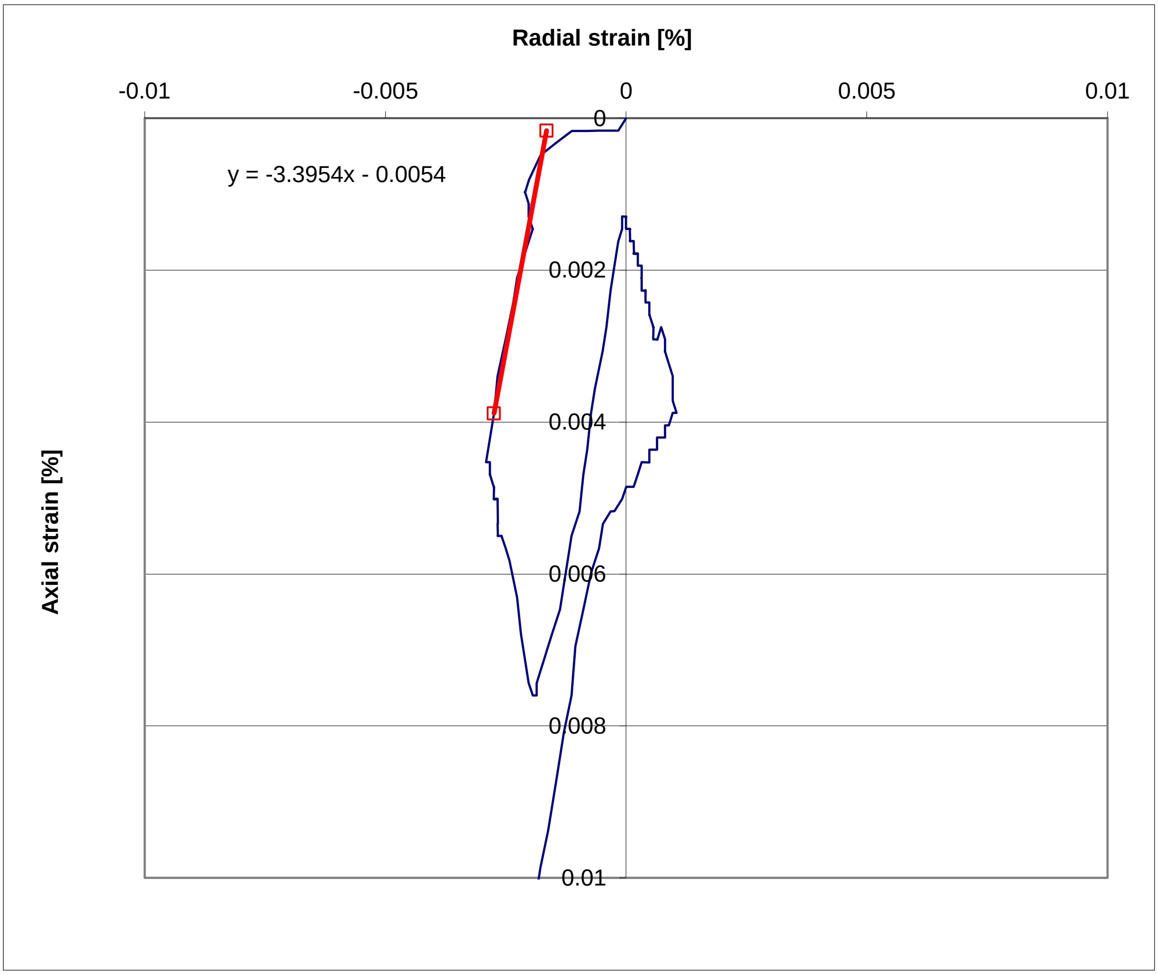
Unconfined Compression Test - UCS



Geology: Induration:	Rastrites	Preparation date: Test date:	10-05-2011 16-05-2011
Sample diameter Sample height	2.477 cm 5.005 cm	Test duration Rate of strain	00:28:00 min. 0.05-0.1 mm/min
Density, ρ	2.48 g/cm3	Comp. Strength, σ_c	67.5 MPa
		Young's modul., E*	10129 MPa
Water cont., w_{after}	3.2 %	Poisson's ratio, ν	0.29
Specimen orientation:	Parallel to core		
Depth Level	20 m --- m	Bor. No. Lab. No.	Billegrav-2 4A

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

Unconfined Compression Test - UCS



Poisson's ratio, ν 0.29

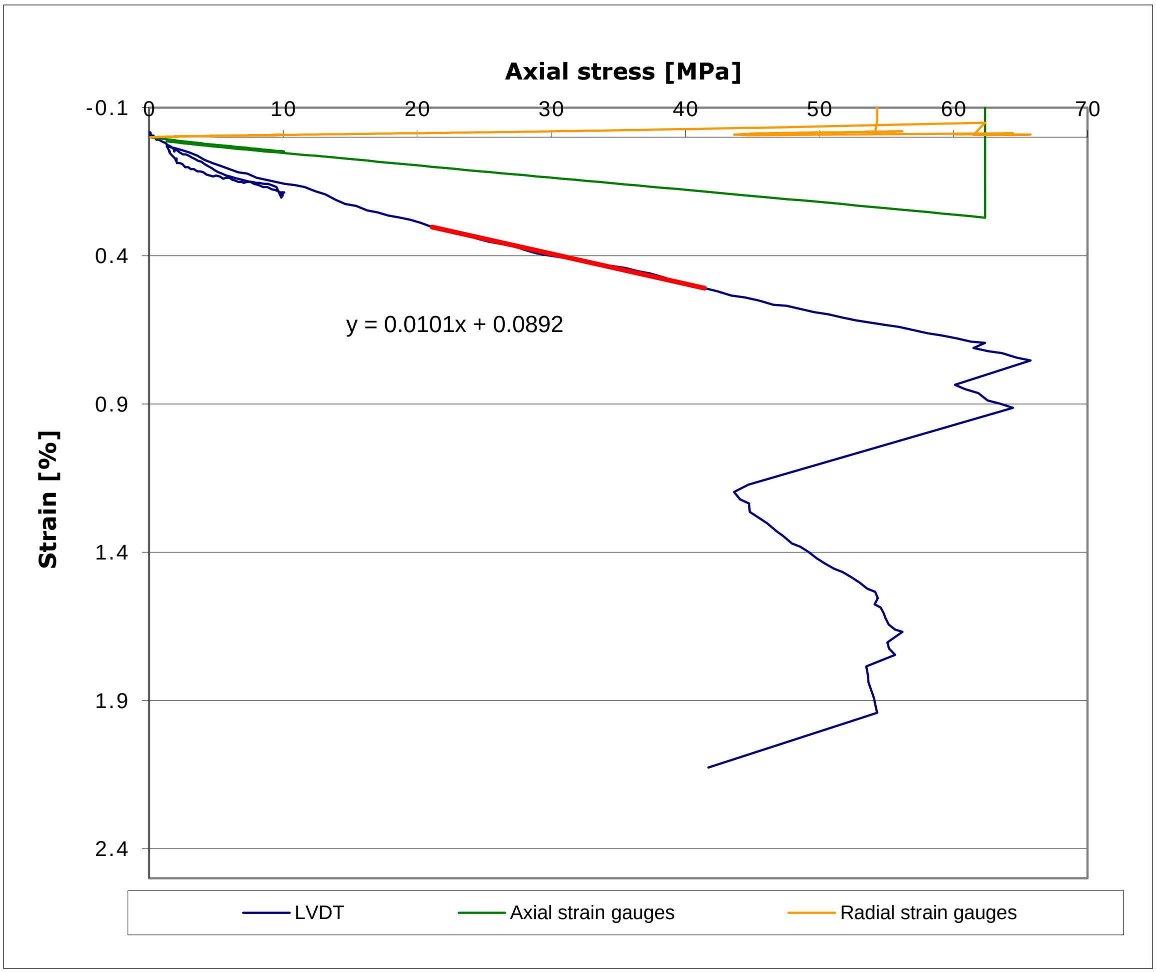
Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

GEO 1 Maglebjergvej, DK-2800 Kgs. Lyngby
Phone:+45 4588 4444, www.geo.dk

Job: 34780 Alun Shale

Prepared:	ILO	Date:	2011-05-17	Subject: UCS	Lab. no.:	4A	
Controlled:	MHO	Date:	2011-05-23				Page 2/2
Approved:	FPD	Date:	2011-06-06	Report 1	Encl.	3	Rev.

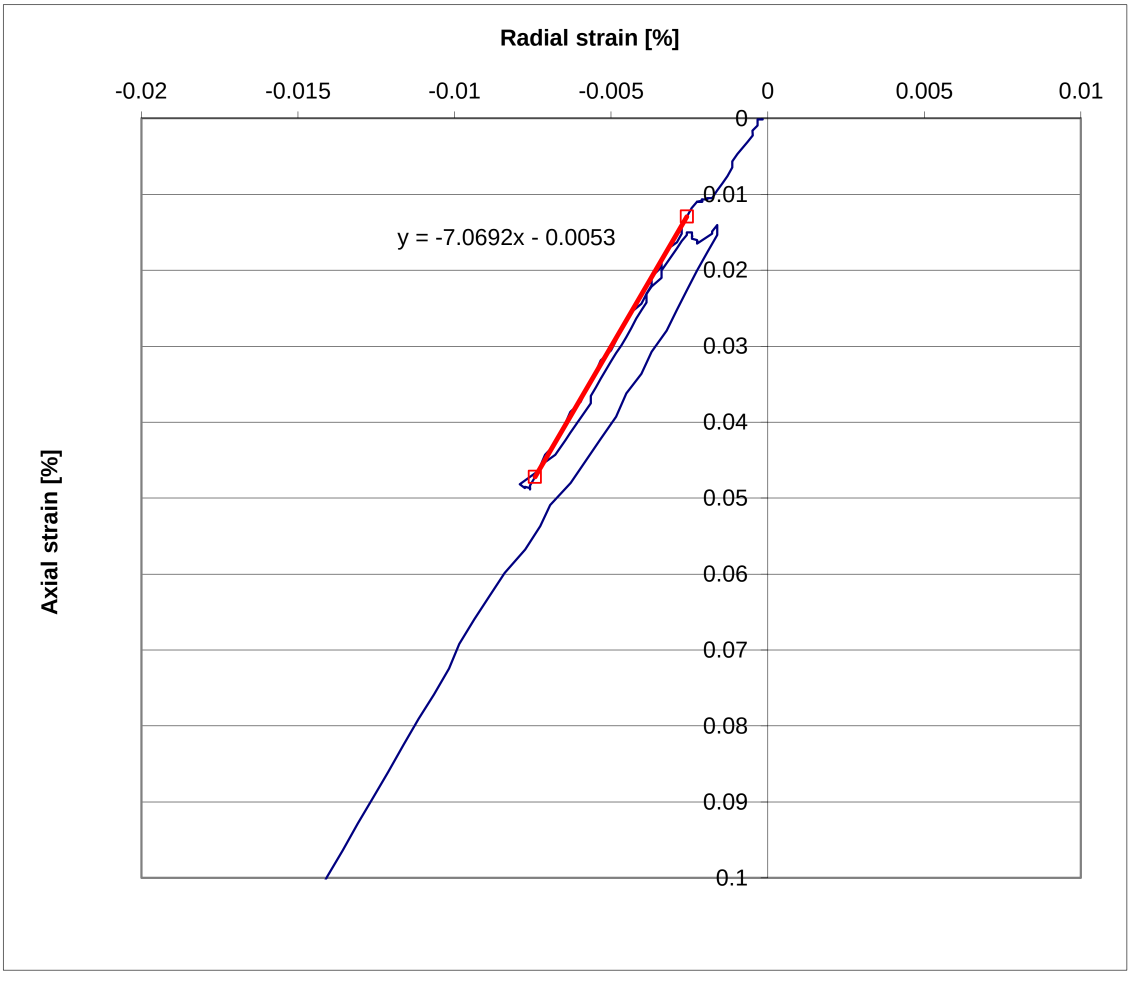
Unconfined Compression Test - UCS



Geology: Rastrites Induration:		Preparation date: 11-05-2011 Test date: 16-05-2011	
Sample diameter	2.471 cm	Test duration	00:21:25 min.
Sample height	3.953 cm	Rate of strain	0.05-0.1 mm/min
Density, ρ	2.48 g/cm3	Comp. Strength, σ_c	65.7 MPa
		Young's modul., E*	9874 MPa
Water cont., w_{after}	2.8 %	Poisson's ratio, ν	0.14
Specimen orientation:	Parallel to core		
Depth	20 m	Bor. No.	Billegrav-2
Level	--- m	Lab. No.	4B

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

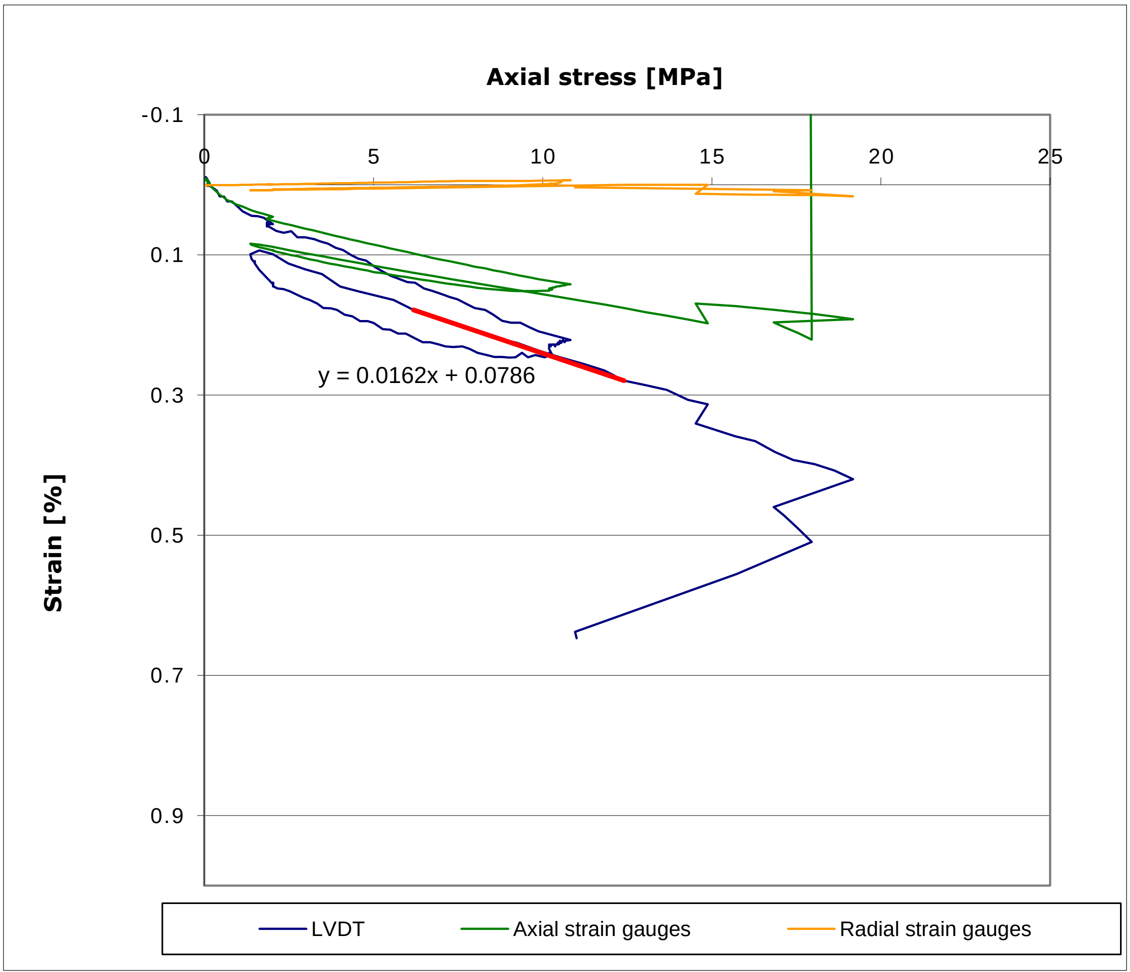
Unconfined Compression Test - UCS



Poisson's ratio, ν 0.14

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

Unconfined Compression Test - UCS



Geology:	Rastrites	Preparation date:	11-05-2011
Induration:		Test date:	17-05-2011
Sample diameter	2.469 cm	Test duration	00:19:05 min.
Sample height	4.586 cm	Rate of strain	0.05-0.1 mm/min
Density, ρ	2.61 g/cm3	Comp. Strength, σ_c	19.2 MPa
		Young's modul., E*	6170 MPa
Water cont., w_{after}	2.0 %	Poisson's ratio, ν	0.08
Specimen orientation:	Parallel to core		
Depth	41 m	Bor. No.	Billegrav-2
Level	--- m	Lab. No.	9A

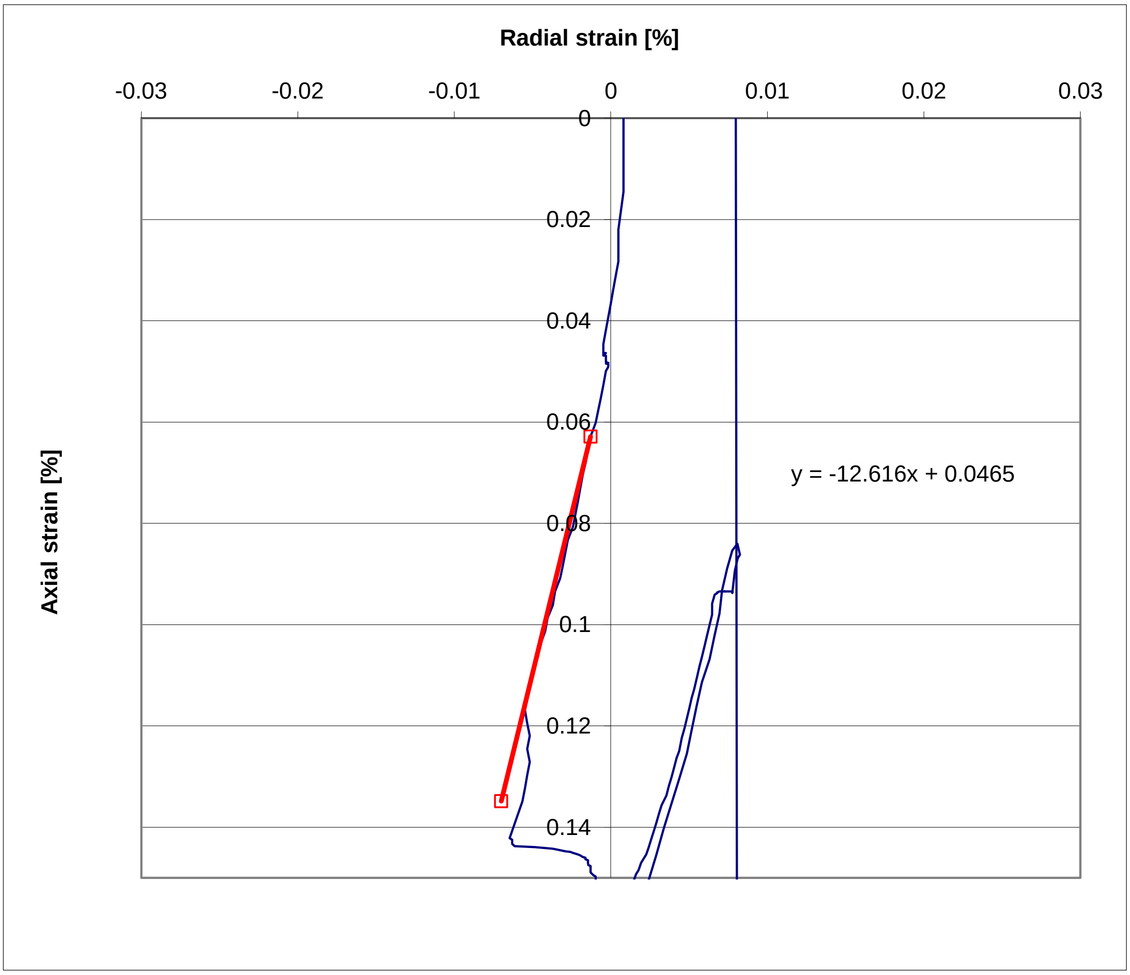
Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

GEO 1 Maglebjergvej, DK-2800 Kgs. Lyngby
Phone:+45 4588 4444, www.geo.dk

Job: 34780 Alun Shale

Prepared:	ILO	Date:	2011-05-17	Subject: UCS	Lab. no.: 9A		
Controlled:	MHO	Date:	2011-05-23				Page 1/2
Approved:	FPD	Date:	2011-06-06	Report 1		Encl. 5	Rev.

Unconfined Compression Test - UCS



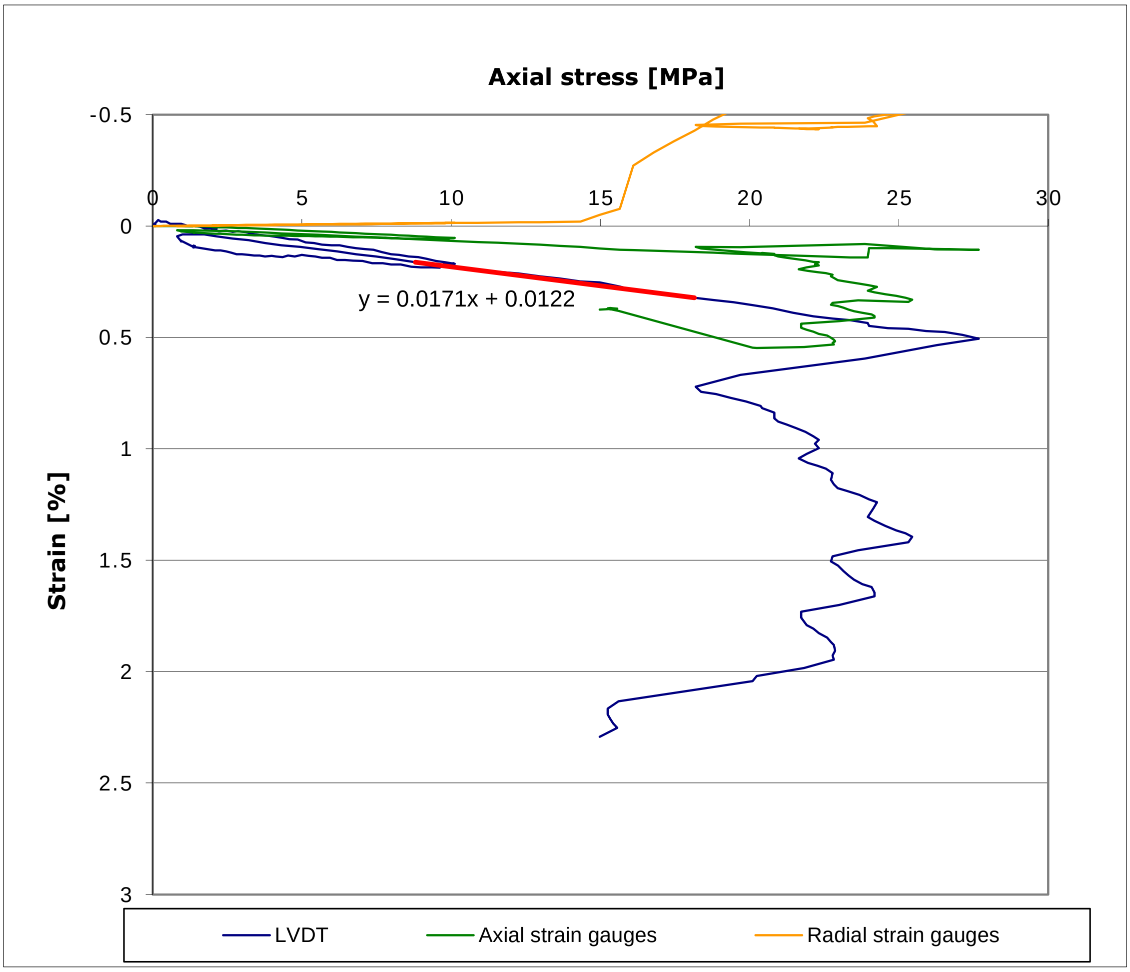
Poisson's ratio, ν 0.08

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

GEO 1 Maglebjergvej, DK-2800 Kgs. Lyngby
Phone:+45 4588 4444, www.geo.dk

			Job: 34780 Alun Shale		
Prepared: ILO	Date:	2011-05-17	Subject: UCS	Lab. no.: 9A	
Controlled: MHO	Date:	2011-05-23			Page 2/2
Approved: FPD	Date:	2011-06-06	Report 1	Encl. 5	Rev.

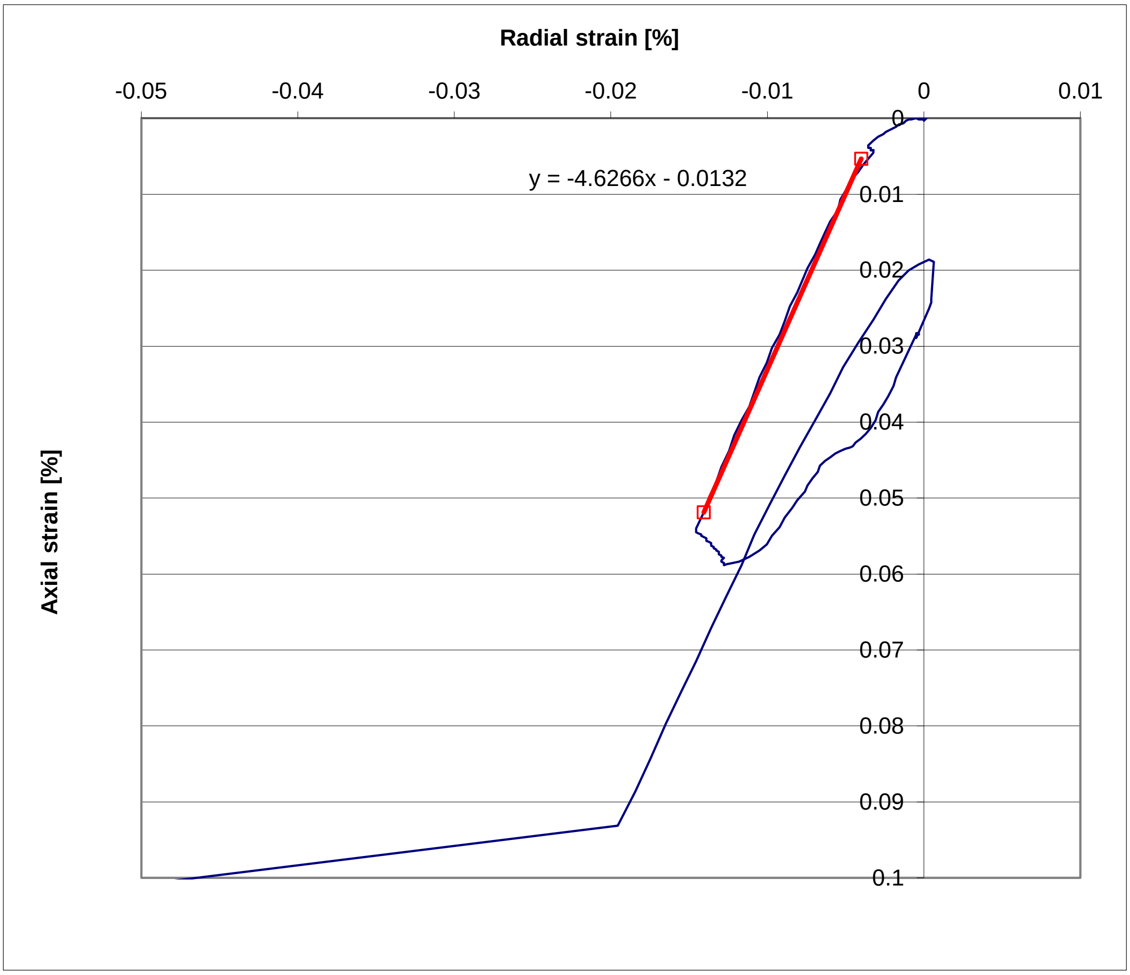
Unconfined Compression Test - UCS



Geology:	Rastrites	Preparation date:	11-05-2011
Induration:		Test date:	17-05-2011
Sample diameter	2.462 cm	Test duration	00:18:50 min.
Sample height	4.220 cm	Rate of strain	0.05-0.1 mm/min
Density, ρ	2.60 g/cm3	Comp. Strength, σ_c	27.7 MPa
		Young's modul., E*	5847 MPa
Water cont., w_{after}	1.9 %	Poisson's ratio, ν	0.22
Specimen orientation:	Parallel to core		
Depth	41 m	Bor. No.	Billegrav-2
Level	--- m	Lab. No.	9B

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

Unconfined Compression Test - UCS



Poisson's ratio, ν 0.22

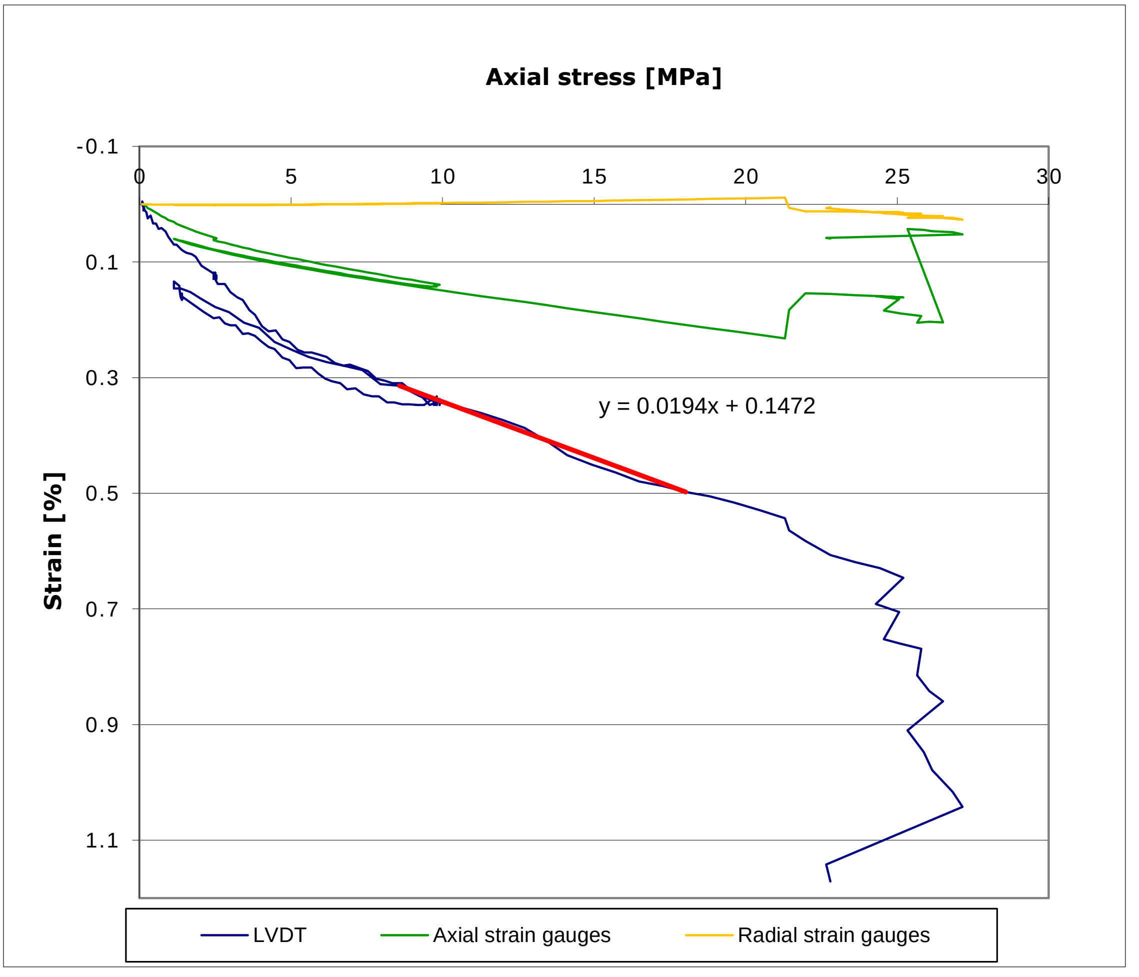
Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

GEO
1 Maglebjergvej, DK-2800 Kgs. Lyngby
Phone:+45 4588 4444, www.geo.dk

Job: 34780 Alun Shale

Prepared: ILO	Date:	2011-05-17	Subject: UCS		Lab. no.:	9B	
Controlled: MHO	Date:	2011-05-23					Page 2/2
Approved: FPD	Date:	2011-06-06	Report	1	Encl.	6	Rev.

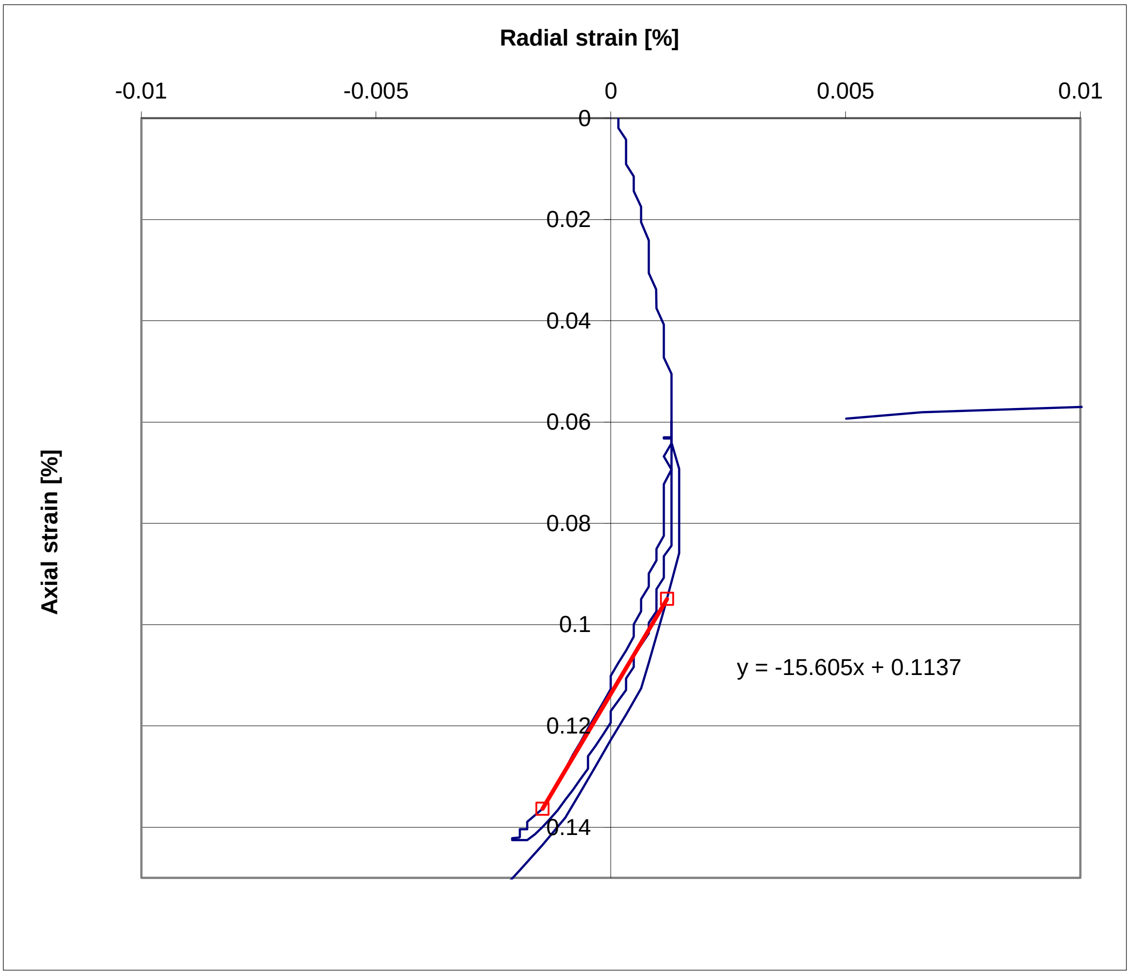
Unconfined Compression Test - UCS



Geology:	Dicellograptus	Preparation date:	17-05-2011
Induration:		Test date:	18-05-2011
Sample diameter	2.461 cm	Test duration	00:19:15 min.
Sample height	3.080 cm	Rate of strain	0.05-0.1 mm/min
Density, ρ	2.51 g/cm3	Comp. Strength, σ_c	27.1 MPa
		Young's modul., E*	5144 MPa
Water cont., w_{after}	2.8 %	Poisson's ratio, ν	0.06
Specimen orientation:	Parallel to core		
Depth	77 m	Bor. No.	Billegrav-2
Level	--- m	Lab. No.	17A

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

Unconfined Compression Test - UCS



Poisson's ratio, ν 0.06

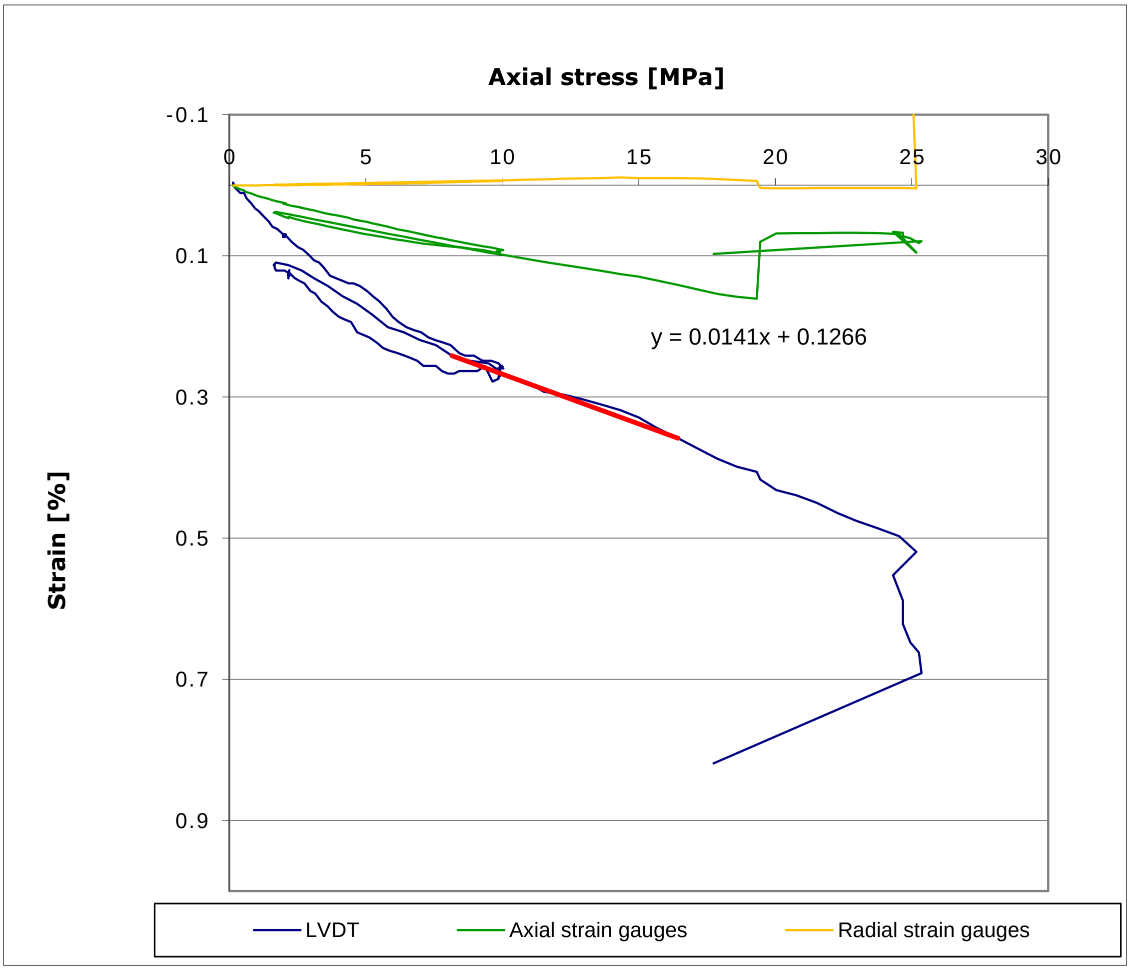
Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

GEO 1 Maglebjergvej, DK-2800 Kgs. Lyngby
Phone:+45 4588 4444, www.geo.dk

Job: 34780 Alun Shale

Prepared: ILO	Date:	2011-05-17	Subject: UCS	Lab. no.: 17A	
Controlled: MHO	Date:	2011-05-23			Page 2/2
Approved: FPD	Date:	2011-06-06	Report 1	Encl. 7	Rev.

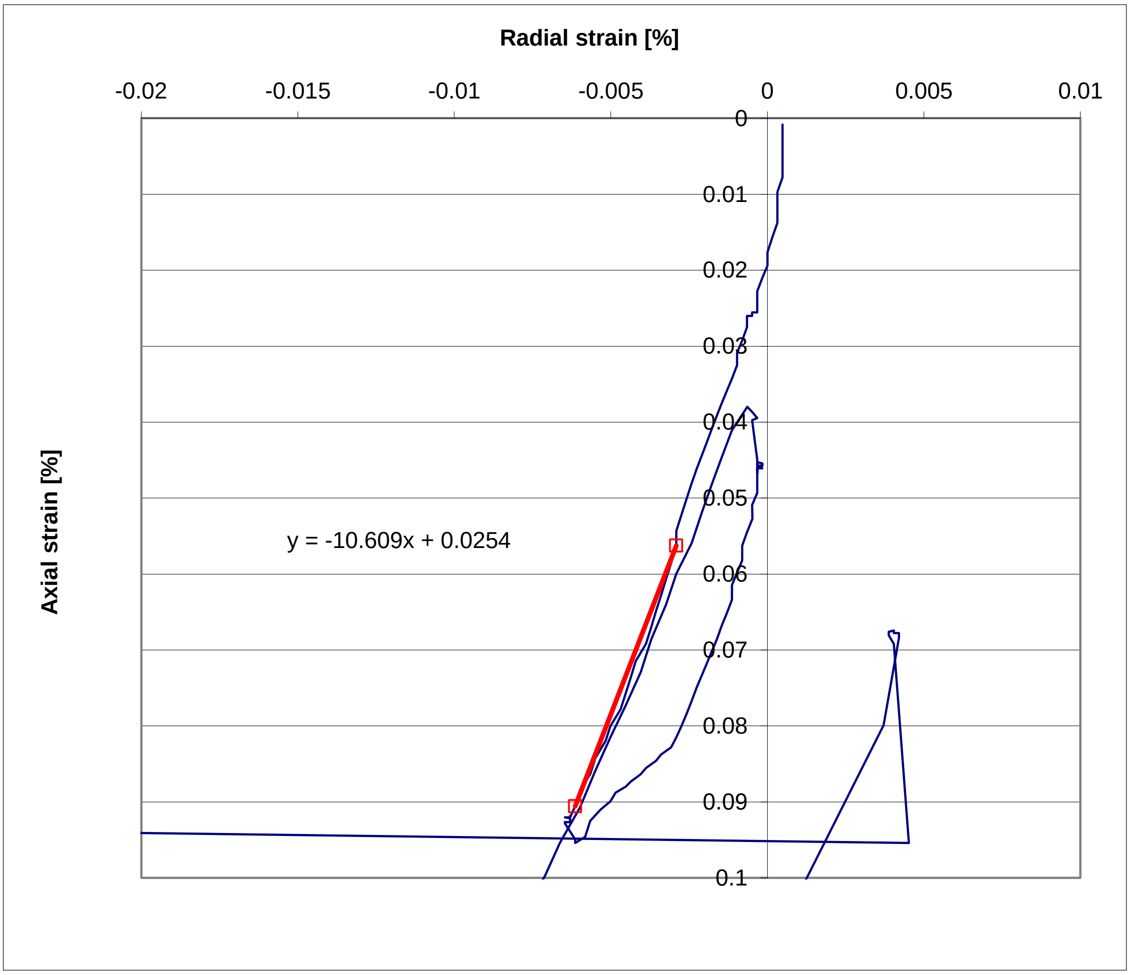
Unconfined Compression Test - UCS



Geology:	Dicellograptus	Preparation date:	17-05-2011
Induration:		Test date:	18-05-2011
Sample diameter	2.471 cm	Test duration	00:18:05 min.
Sample height	3.832 cm	Rate of strain	0.05-0.1 mm/min
Density, ρ	2.49 g/cm3	Comp. Strength, σ_c	25.4 MPa
		Young's modul., E*	7090 MPa
Water cont., w_{after}	2.9 %	Poisson's ratio, ν	0.09
Specimen orientation:	Parallel to core		
Depth	77 m	Bor. No.	Billegrav-2
Level	--- m	Lab. No.	17B

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

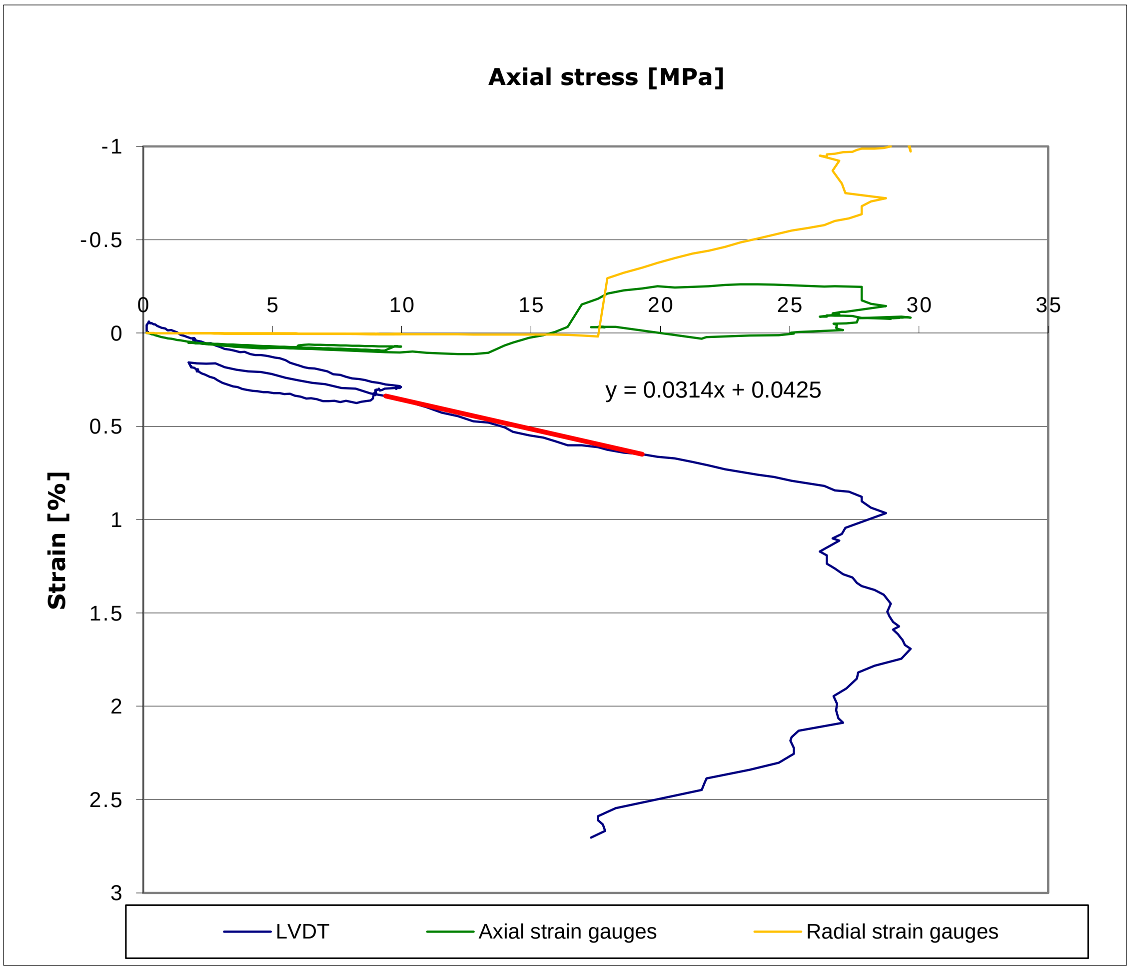
Unconfined Compression Test - UCS



Poisson's ratio, ν 0.09

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

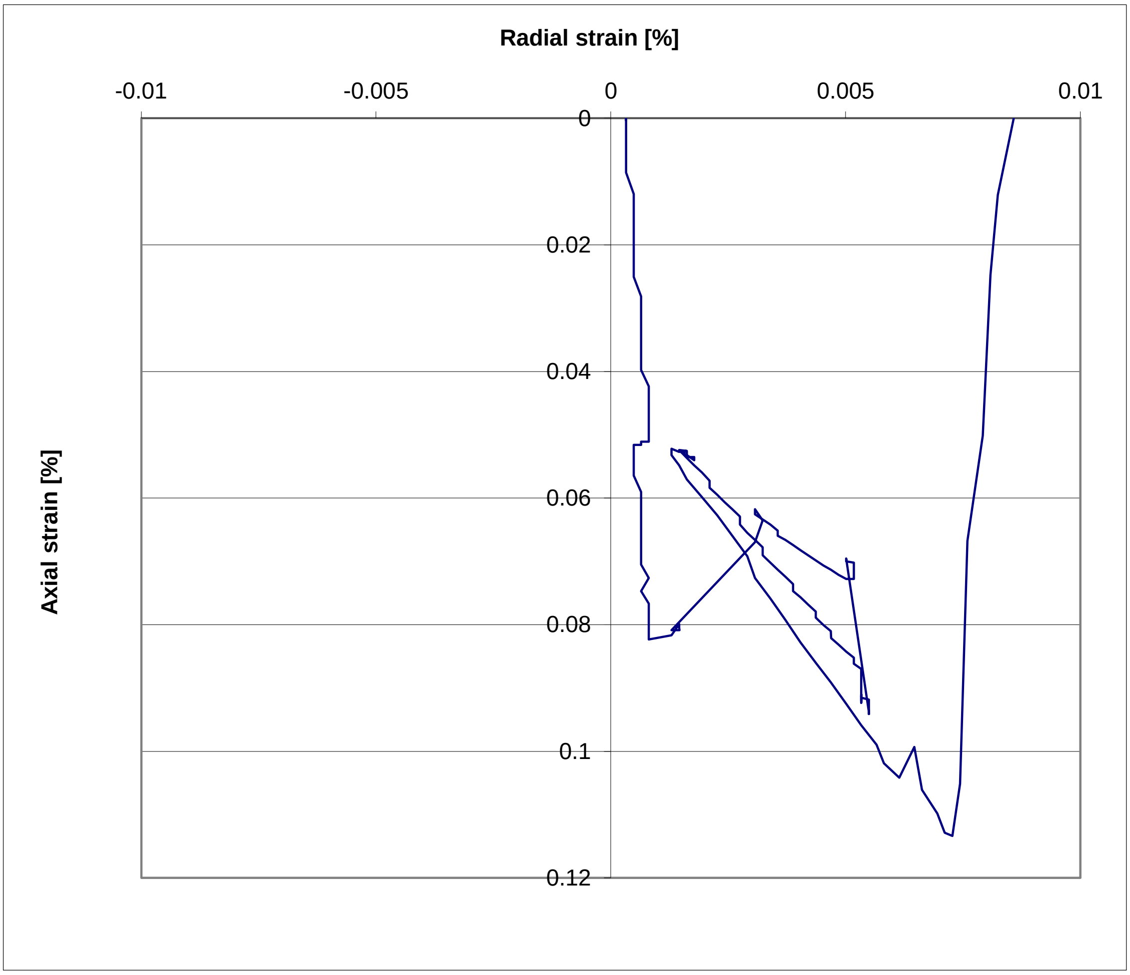
Unconfined Compression Test - UCS



Geology:	Dicellograptus	Preparation date:	18-05-2011
Induration:		Test date:	18-05-2011
Sample diameter	2.469 cm	Test duration	00:22:40 min.
Sample height	2.995 cm	Rate of strain	0.05-0.1 mm/min
Density, ρ	2.47 g/cm3	Comp. Strength, σ_c	29.7 MPa
		Young's modul., E*	3183 MPa
Water cont., w_{after}	2.8 %	Poisson's ratio, ν	---
Specimen orientation:	Parallel to core		
Depth	77 m	Bor. No.	Billegrav-2
Level	--- m	Lab. No.	17C

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

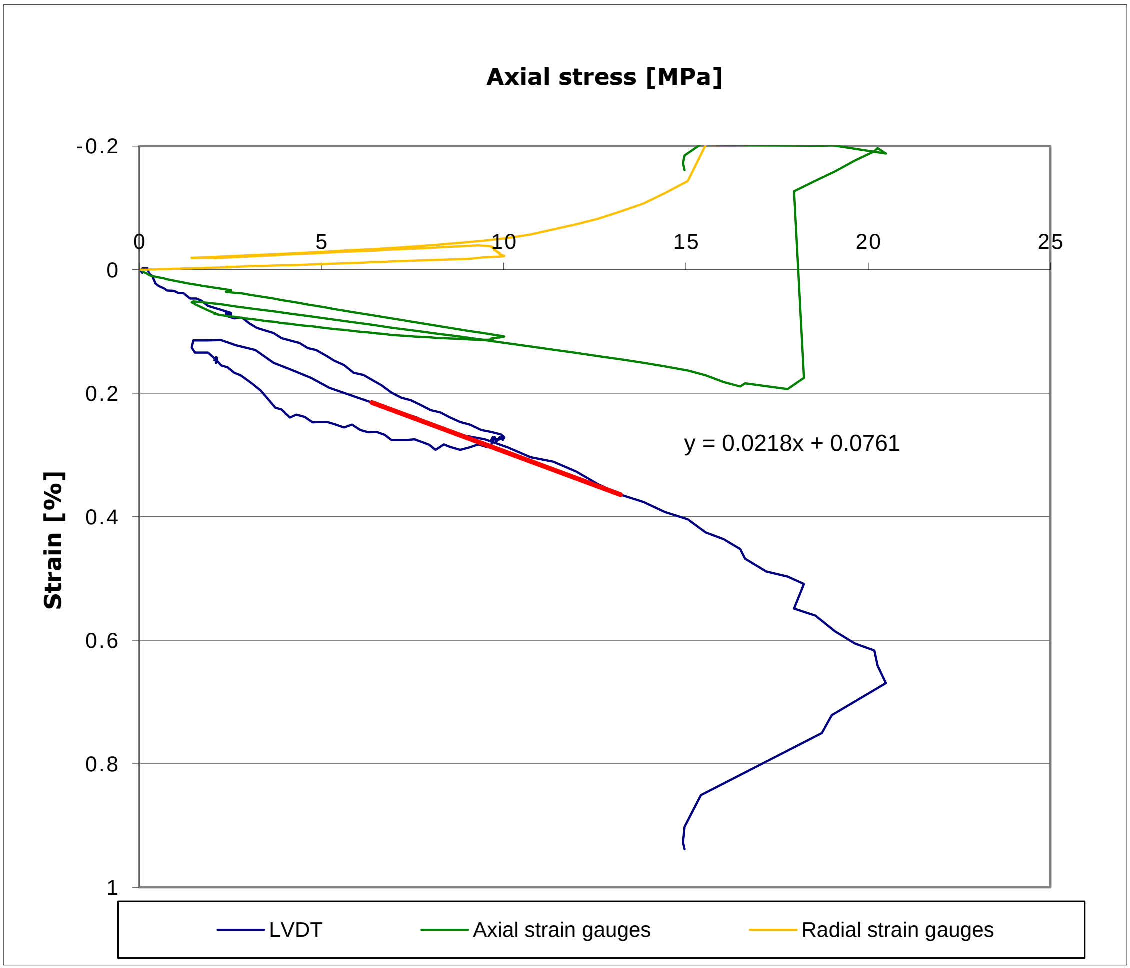
Unconfined Compression Test - UCS



Poisson's ratio, ν ---

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

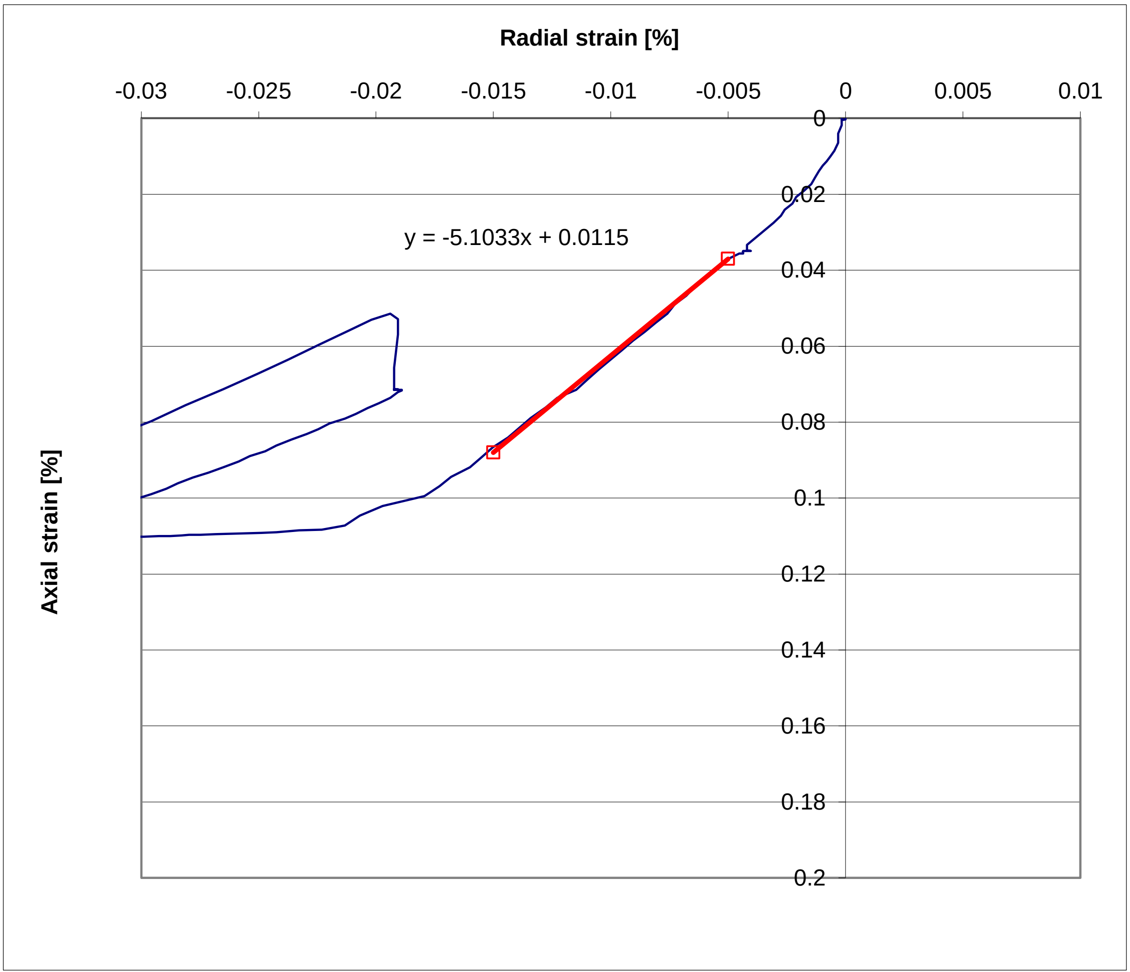
Unconfined Compression Test - UCS



Geology:	Alúm	Preparation date:	10-05-2011
Induration:		Test date:	18-05-2011
Sample diameter	2.474 cm	Test duration	00:18:20 min.
Sample height	3.486 cm	Rate of strain	0.05-0.1 mm/min
Density, ρ	2.49 g/cm3	Comp. Strength, σ_c	20.5 MPa
		Young's modul., E*	4588 MPa
Water cont., w_{after}	2.7 %	Poisson's ratio, ν	0.20
Specimen orientation:	Parallel to core		
Depth	98.86 m	Bor. No.	Billegrav-2
Level	--- m	Lab. No.	22A

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

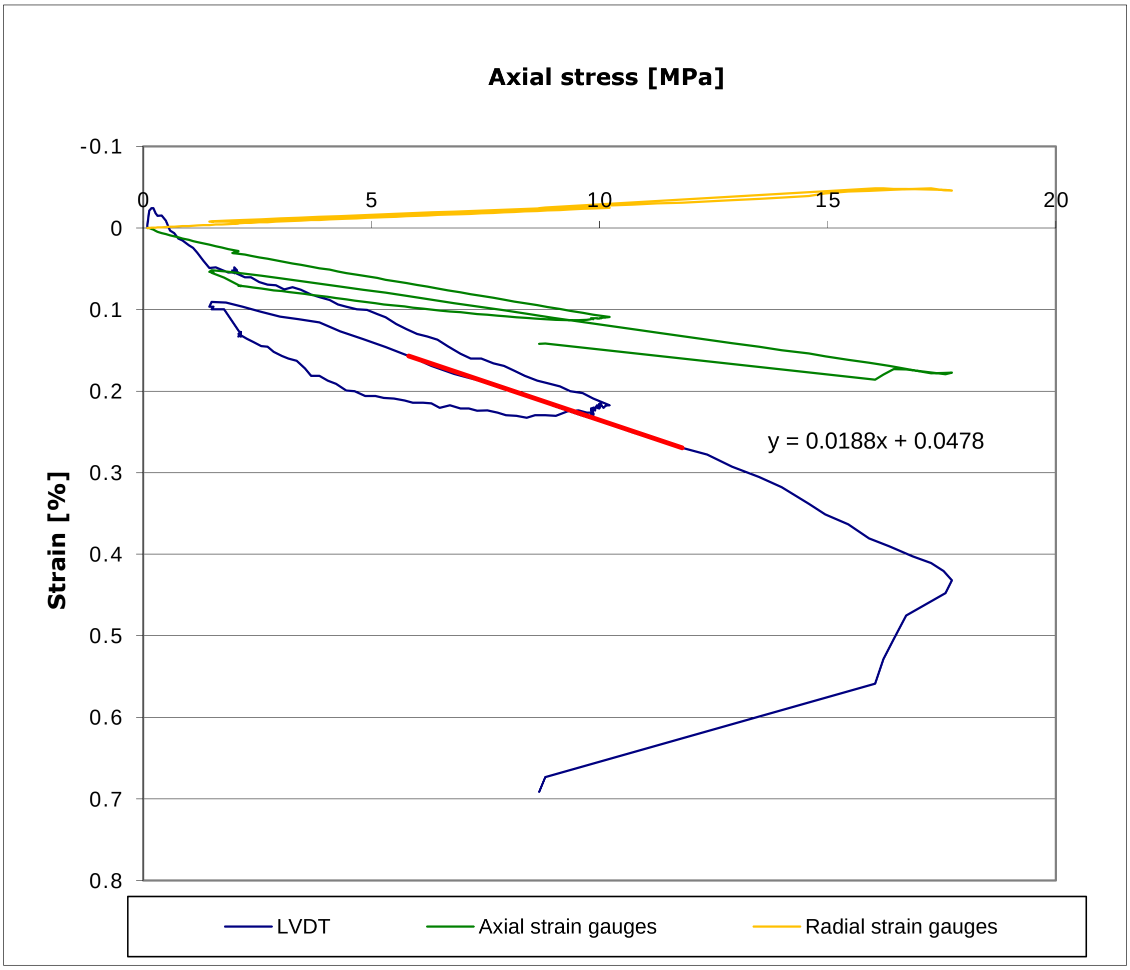
Unconfined Compression Test - UCS



Poisson's ratio, ν 0.20

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

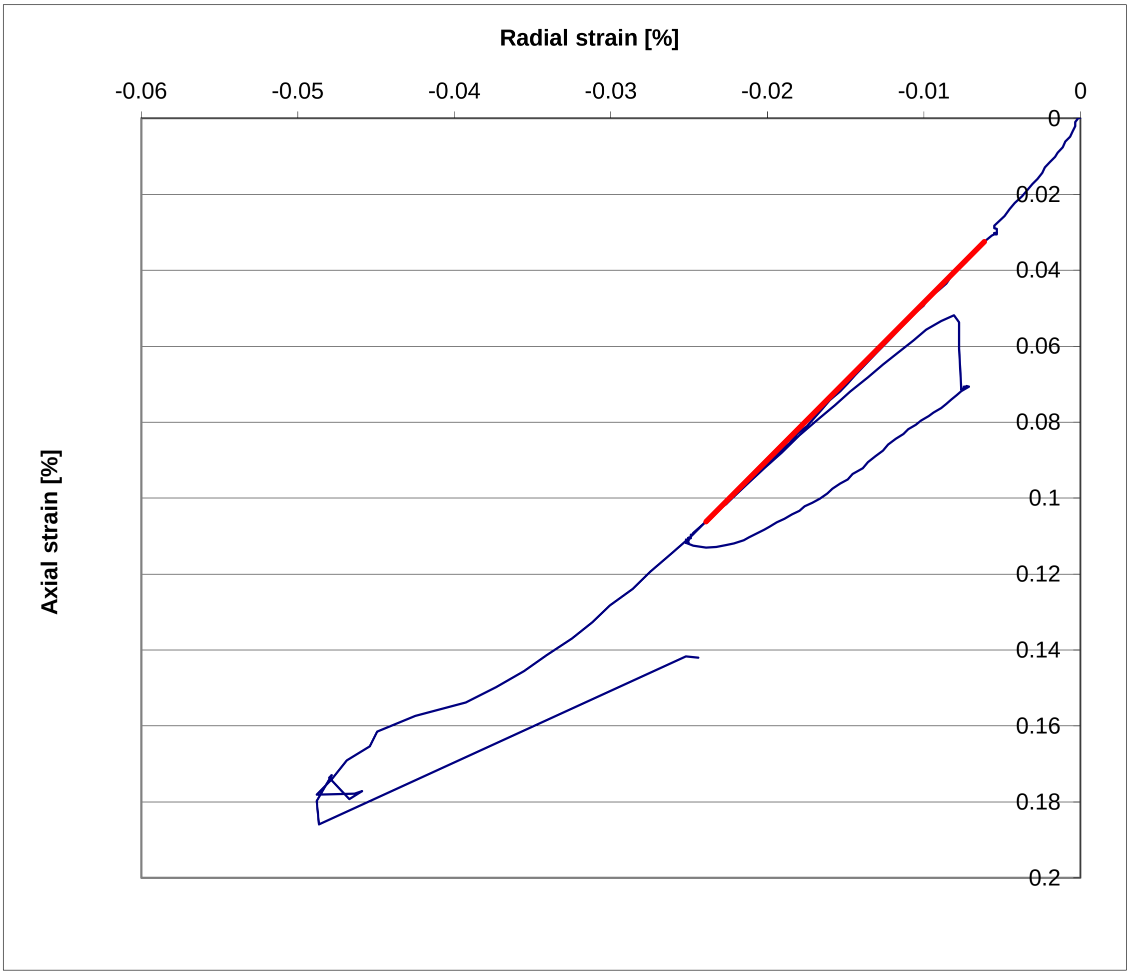
Unconfined Compression Test - UCS



Geology:	Alúm	Preparation date:	12-05-2011
Induration:		Test date:	18-05-2011
Sample diameter	2.460 cm	Test duration	00:18:55 min.
Sample height	4.642 cm	Rate of strain	0.05-0.1 mm/min
Density, ρ	2.46 g/cm3	Comp. Strength, σ_c	17.7 MPa
		Young's modul., E*	5324 MPa
Water cont., w_{after}	2.6 %	Poisson's ratio, ν	0.24
Specimen orientation:	Parallel to core		
Depth	98.81 m	Bor. No.	Billegrav-2
Level	--- m	Lab. No.	22C

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

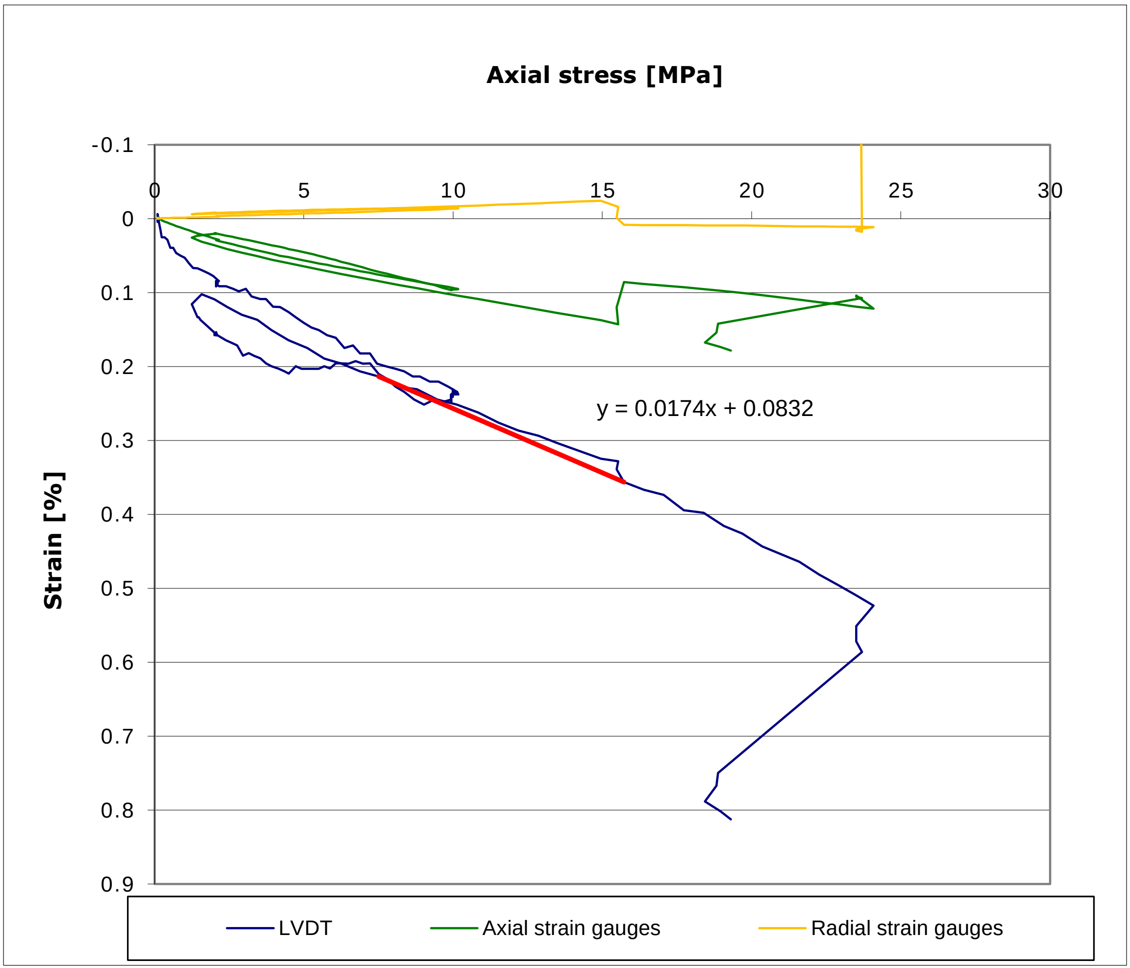
Unconfined Compression Test - UCS



Poisson's ratio, ν 0.24

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

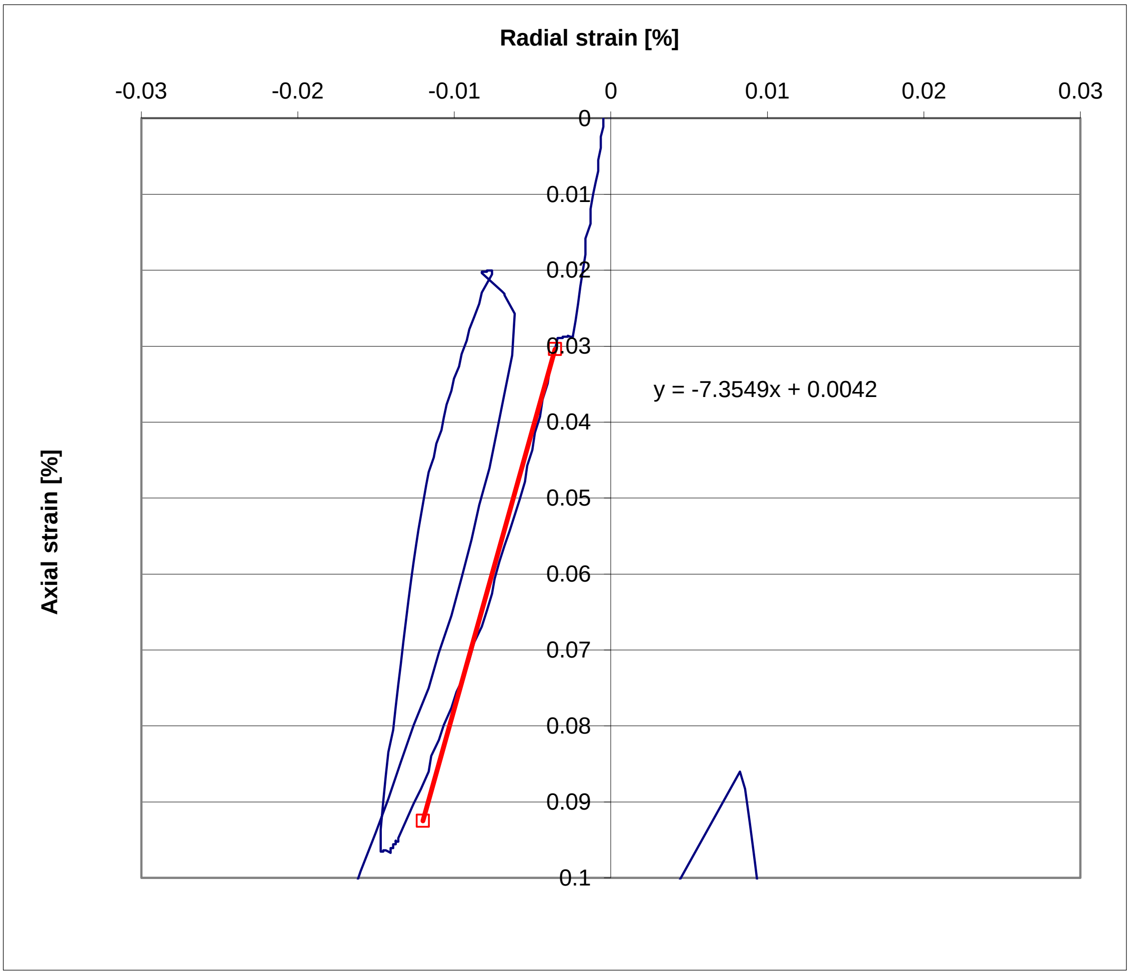
Unconfined Compression Test - UCS



Geology:	Alúm	Preparation date:	10-05-2011
Induration:		Test date:	17-05-2011
Sample diameter	2.399 cm	Test duration	00:19:55 min.
Sample height	4.025 cm	Rate of strain	0.05-0.1 mm/min
Density, ρ	2.68 g/cm3	Comp. Strength, σ_c	24.1 MPa
		Young's modul., E*	5757 MPa
Water cont., w_{after}	2.5 %	Poisson's ratio, ν	0.14
Specimen orientation:	Parallel to core		
Depth	115.67 m	Bor. No.	Billegrav-2
Level	--- m	Lab. No.	28A

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

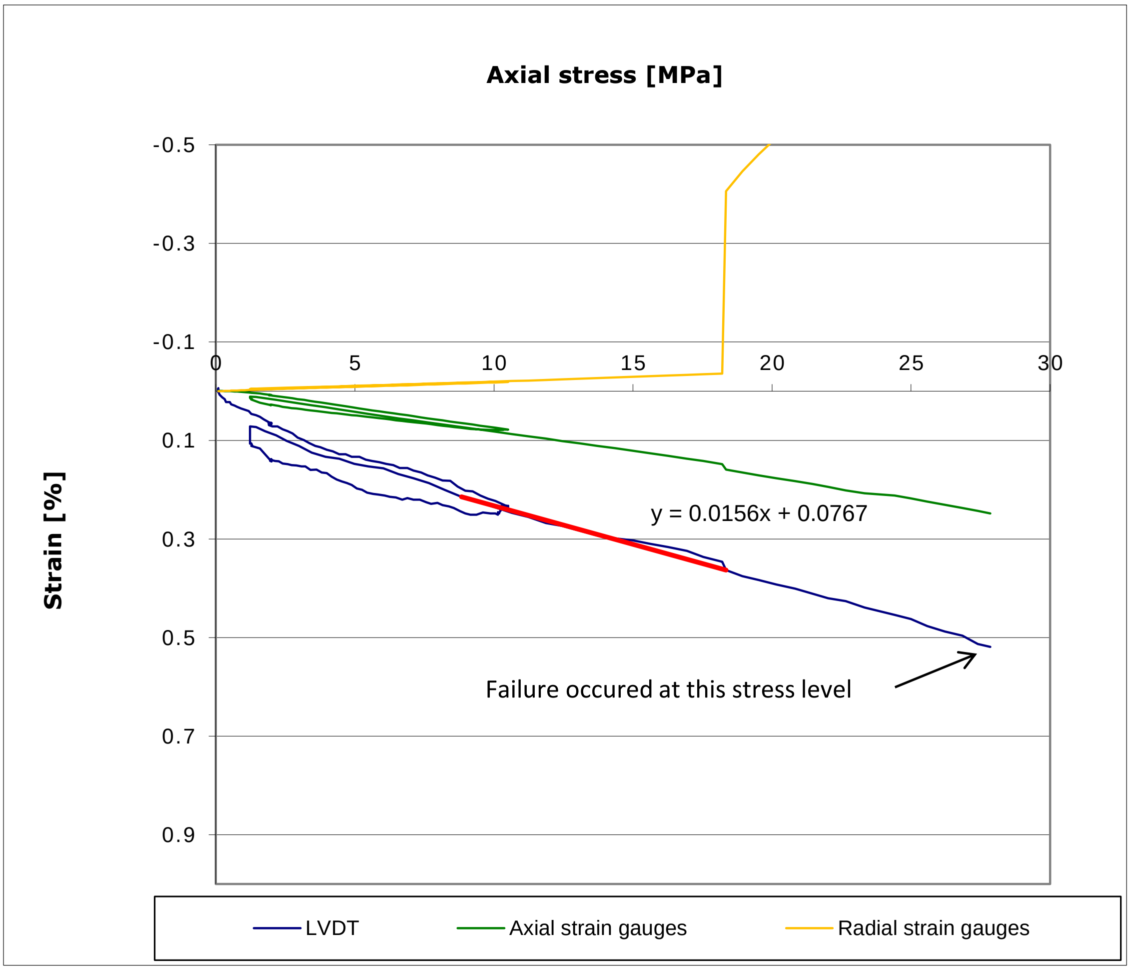
Unconfined Compression Test - UCS



Poisson's ratio, ν 0.14

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

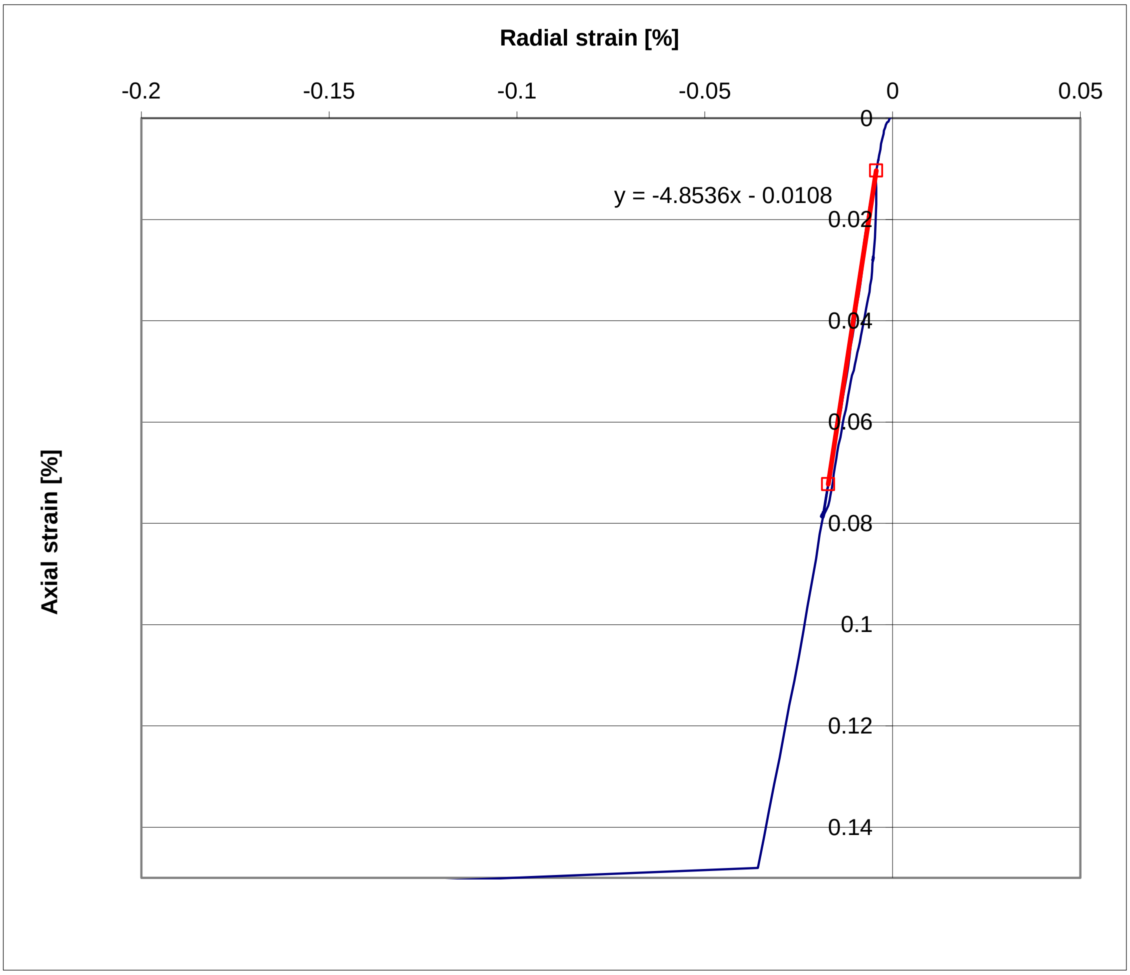
Unconfined Compression Test - UCS



Geology:	Alúm	Preparation date:	11-05-2011
Induration:		Test date:	17-05-2011
Sample diameter	2.464 cm	Test duration	00:20:10 min.
Sample height	4.996 cm	Rate of strain	0.05-0.1 mm/min
Density, ρ	2.61 g/cm3	Comp. Strength, σ_c	27.9 MPa
		Young's modul., E*	6402 MPa
Water cont., w_{after}	2.4 %	Poisson's ratio, ν	0
Specimen orientation:	Parallel to core		
Depth	115.67 m	Bor. No.	Billegrav-2
Level	--- m	Lab. No.	28B

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

Unconfined Compression Test - UCS



Poisson's ratio, ν 0.21

Test is performed in accordance with ISRM, Suggested Method, part 1 and part 2, pp.153 (2007)

GEO 1 Maglebjergvej, DK-2800 Kgs. Lyngby
Phone:+45 4588 4444, www.geo.dk

Job: 34780 Alun Shale

Prepared:	ILO	Date:	2011-05-17	Subject: UCS	Lab. no.:	28B		
Controlled:	MHO	Date:	2011-05-23					Page 2/2
Approved:	FPD	Date:	2011-06-06	Report	1	Encl.	13	Rev.

Tensile strength test results

Well: Billegrav-2

Well	Lab no.	Geology	Induration	ϕ	Strain rate	Specimen dimensions: Diameter	Height	Volume	ρ_{bulk}	w	σ_t	σ_t
				%	mm/min	cm	cm	cm^3	g/cm^3	%	MPa	PSI
Billegrav-2	5	Rastrites			0.20	5.59	2.68	65.67	2.50	2.5	2.63	381
Billegrav-2	10A	Rastrites			0.20	5.58	2.70	66.10	2.57	2.4	2.75	399
Billegrav-2	10B	Rastrites			0.20	5.58	2.71	66.20	2.57	2.5	6.19	898
Billegrav-2	19A	Dicellograptus			0.20	5.59	2.72	66.71	2.63	1.5	11.47	1663
Billegrav-2	19B	Dicellograptus			0.20	5.59	2.51	61.43	2.59	1.7	4.69	680
Billegrav-2	21A	Alúm			0.20	5.60	2.74	67.51	2.45	2.6	4.32	626
Billegrav-2	21B	Alúm			0.20	5.59	2.76	67.66	2.47	2.6	3.37	489
Billegrav-2	24A	Alúm			0.20	5.58	2.70	66.03	2.47	3.3	2.35	341
Billegrav-2	24B	Alúm			0.20	5.58	2.73	61.59	2.56	3.2	4.46	647
Billegrav-2	27	Alúm			0.20	5.59	2.60	63.81	2.51	2.7	3.52	511

Test is performed in accordance with ISRM, Suggested Method, part 2, pp. 182 (2007)

Appendix D: Vp and Vs measurements

Vp measurements

Sample	ID	Orientation	Depth (top)	Formation	Density	Load	Vp	Load	Vp	Load	Vp	Load	Vp	Load	Vp	Load	Vp	AVG VP 3-7 Mpa	AVG VP 7-10 Mpa
			M		g/cm3	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	km/s	km/s
1	1A	45	5.18	Rastrites	2.64														
	1B	Vertical		Rastrites	2.58	5	3.50	5	3.57									3.54	
6	6A	45	24.80	Rastrites	2.55	5	3.51	5	3.51	10	3.54	10	3.54					3.51	3.54
	6B	Vertical		Rastrites	2.53	5	3.52	5	3.52	10	3.62	10	3.62					3.52	3.62
	6C	Horizontal		Rastrites	2.56	5	4.39	5	4.39	10	4.45	10	4.45					4.39	4.45
8	8A	45	35.00	Rastrites	2.56	5	4.61	5	4.61	10	4.61	10	4.61					4.61	4.61
	8B	Vertical		Rastrites	2.62	5	3.95	5	3.95	10	4.01	10	4.01					3.95	4.01
	8C	Horizontal		Rastrites	2.61	5	4.67	5	4.67	5	4.56	5	4.56	10	4.56	10	4.56	4.61	4.56
11	11A	45	44.90	Rastrites	2.63	5	4.41	5	4.41	10	4.45	10	4.45					4.41	4.45
	11B	Vertical		Rastrites	2.63	5	4.39	5	4.39	10	4.44	10	4.39					4.39	4.42
	11C	Horizontal		Rastrites	2.61	5	4.62	5	4.62	10	4.80							4.62	4.80
	11D	Horizontal		Rastrites	2.61	5	4.07	5	4.07									4.07	
12	12A	45	50.82	Rastrites	2.46	3	4.24												
	12B	Vertical		Rastrites	2.53	5	3.82	5	3.91	10	4.09							3.87	4.09
	12C	Horizontal		Rastrites	2.51	5	4.46	5	4.46	10	4.71	10	4.71					4.46	4.71
13	#	Vertical	56.52	Rastrites	2.59	5	4.08	5	4.08	10	4.21	10	4.21					4.08	4.21
14	14A	45	61.30	Lindegård	2.65														
	14B	Vertical		Lindegård	2.62	5	4.41	5	4.41	5	4.41	10	4.54	10	4.54			4.41	4.54
	14C	Horizontal		Lindegård	2.51	5	5.15	5	5.15	10	5.34	10	5.34					5.15	5.34
15	15A	45	69.39	Lindegård	2.71	5	4.40	5	4.40	10	4.45	10	4.45					4.40	4.45
	15B	Vertical		Lindegård	2.68	5	4.07	5	4.13	10	4.19	10	4.19					4.10	4.19

Sample	ID	Orientation	Depth (top)	Formation	Density	Load	Vp	Load	Vp	Load	Vp	Load	Vp	AVG VP 3-7 Mpa	AVG VP 7-10 Mpa
			M		g/cm3	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	km/s	km/s
	15C	Horizontal		Lindegård	2.65	5	5.20	5	5.20	10	5.20			5.20	5.20
16	16A	45	74.90	Dicellograptus	2.29	5	3.85	5	3.91					3.88	
	16B	45		Dicellograptus	2.50	5	3.93	5	3.93					3.93	
	16C	Vertical		Dicellograptus	2.55	5	3.80	5	3.80	10	3.90	10	3.90	3.80	3.90
	16D	Horizontal		Dicellograptus	2.45	5	4.57	5	4.57					4.57	
18	18A	45	80.40	Dicellograptus	2.46	5	4.09	5	4.09	9	4.14	9	4.14	4.09	4.14
	18B	Vertical		Dicellograptus	2.52	5	4.12	5	4.12	10	4.18	10	4.18	4.12	4.18
	18C	Horizontal		Dicellograptus	2.48	5	4.32	5	4.32	10	4.47	10	4.47	4.32	4.47
20	20A	45	93.40	Alum	2.60	7	4.72	7	4.72	10	4.77	10	4.72	4.72	4.75
	20C	Horizontal		Alum	2.58	5	5.31	5	5.31	10	5.31	10	5.31	5.31	5.31
23	23B	Vertical	101.50	Alum	2.31	5	3.18	5	3.18	10	3.25			3.18	3.25
	23C	Horizontal		Alum	2.30	7	4.46	7	4.46	10	4.46	10	4.46	4.46	4.46
25	25A	45	105.80	Alum	2.44										
	25B	Vertical		Alum	2.50	5	3.21	5	3.21	10	3.26	10	3.26	3.21	3.26
26	26A	45	110.90	Alum	2.42	5	3.64	5	3.64	10	3.72	10	3.72	3.64	3.72
	26B	Vertical		Alum	2.41	5	3.31	5	3.31	10	3.39	10	3.39	3.31	3.39
	26C	Horizontal		Alum	2.55	5	4.07	5	4.16	10	4.16	10	4.16	4.12	4.16
29	29A	45	116.78	Alum	2.58	5	3.77	5	3.77	10	3.80	10	3.80	3.77	3.80
	29B	Vertical		Alum	2.58	5	3.47	5	3.47	10	3.47	10	3.47	3.47	3.47
	29C	Horizontal		Alum	2.55	6	4.39	6	4.39	10	4.46	10	4.46	4.39	4.46
30	30A	45	119.80	Alum	2.59										
	30C	Horizontal		Alum	2.59	5	4.79	5	4.79	10	4.79	10	4.79	4.79	4.79

Appendix D: Vs measurements

Sample	ID	Orientation	Depth (top)	Formation	Density	Load	VS1	Load	VS1	Load	VS1	Load	VS1	Load	VS1	AVG VS1 5-7 Mpa	AVG VS1 9-10 Mpa
			m		g/cm3	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	km/s	km/s
1	1A	45.00	5.18	Rastrites	2.64												
	1B	Vertical		Rastrites	2.58	5	2.38										
6	6A	45.00	24.80	Rastrites	2.55	5	2.59	5	2.58	10	2.58	10	2.55			2.58	2.56
	6B	Vertical		Rastrites	2.53	5	1.65			10	1.91					1.65	1.91
	6C	Horizontal		Rastrites	2.56	5	2.40	5	2.40	10	2.42	10	2.40			2.40	2.41
8	8A	45.00	35.00	Rastrites	2.56	5	2.11			10	2.05					2.11	2.05
	8B	Vertical		Rastrites	2.62	5	2.18	5	2.15	10	2.20	10	2.20			2.17	2.20
	8C	Horizontal		Rastrites	2.61	5	2.53	5	2.33	5	2.23					2.37	
11	11A	45	44.90	Rastrites	2.63	5	3.16	5	3.16	10	3.19	10	3.19			3.16	3.19
	11B	Vertical		Rastrites	2.63	5	2.16	5	2.17	10	2.20	10	2.21			2.16	2.20
	11C	Horizontal		Rastrites	2.61	5	1.83									1.83	
	11D	Horizontal		Rastrites	2.61	5	1.96									1.96	
12	12A	45	50.82	Rastrites	2.46												
	12B	Vertical		Rastrites	2.53	5	1.34			10	1.37					1.34	1.37
	12C	Horizontal		Rastrites	2.51	5	2.20			10	2.20					2.20	2.20
13	13	Vertical	56.52	Rastrites	2.59					10	1.79						1.79
14	14A	45	61.30	Lindegård	2.65												
	14B	Vertical		Lindegård	2.62					5	2.14	10	2.30	10	2.30	2.14	2.30
	14C	Horizontal		Lindegård	2.51			5	2.44			10	2.48			2.44	2.48
15	15A	45	69.39	Lindegård	2.71	5	3.22	5	3.25	10	3.25	10	3.28			3.24	3.27
	15B	Vertical		Lindegård	2.68	5	2.09	5	2.08	10	2.06	10	2.08			2.09	2.07

Sample	ID	Orientation	Depth (top)	Formation	Density	Load	VS1	Load	VS1	Load	VS1	Load	VS1	Load	VS1	AVG VS1 5-7 Mpa	AVG VS1 9-10 Mpa
			m		g/cm3	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	km/s	km/s
	15C	Horizontal		Lindegård	2.65	5	3.23	5	2.14	10	3.23					2.69	3.23
16	16A	45	74.90	Dicellograptus	2.29	5	2.02	5	2.02							2.02	
	16B	45		Dicellograptus	2.50			5	1.37							1.37	
	16C	Vertical		Dicellograptus	2.55			5	2.36			10	1.90			2.36	1.90
	16D	Horizontal		Dicellograptus	2.45	5	2.73	5	2.71							2.72	
18	18A	45	80.40	Dicellograptus	2.46	5	2.45	5	2.43	9	2.96	9	2.09			2.44	2.52
	18B	Vertical		Dicellograptus	2.52	5	1.97	5	1.94	10	2.06	10	2.06			1.95	2.06
	18C	Horizontal		Dicellograptus	2.48			5	1.68			10	1.64			1.68	1.64
20	20A	45	93.40	Dicellograptus	2.60	7	2.45	7	2.45	10	2.42	10	2.40			2.45	2.41
	20C	Horizontal		Dicellograptus	2.58			5	2.76			10	2.81			2.76	2.81
23	23B	Vertical	101.50	Alum	2.31	5	1.48	5	1.48	10	1.49					1.48	1.49
	23C	Horizontal		Alum	2.30			7	2.38			10	1.98			2.38	1.98
25	25A	45	105.80	Alum	2.44												
	25B	Vertical		Alum	2.50	5	1.27	5	1.26	10	1.59	10	1.59			1.26	1.59
26	26A	45	110.90	Alum	2.42	5	1.44	5	1.44	10	1.57	10	1.57			1.44	1.57
	26B	Vertical		Alum	2.41			5	1.75			10	1.69			0.88	1.69
	26C	Horizontal		Alum	2.55	5	2.86	5	2.86	10	2.86	10	2.86			2.86	2.86

Sample	ID	Orientation	Depth (top)	Formation	Density	Load	VS1	Load	VS1	Load	VS1	Load	VS1	Load	VS1	AVG VS1 5-7 Mpa	AVG VS1 9-10 Mpa
			m		g/cm3	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	km/s	km/s
29	29A	45	116.78	Alum	2.58	5	2.69	5	2.65	10	2.68	10	2.66			2.67	2.66
	29B	Vertical		Alum	2.58	5	1.72	5	1.75	10	1.72	10	1.72			1.73	1.72
	29C	Horizontal		Alum	2.55	6	2.66	6	2.66	10	2.35	10	2.35			2.66	2.35
30	30A	45	119.80	Alum	2.59												
	30C	Horizontal		Alum	2.59	5	2.71	5	2.30	10	2.95	10	2.89			2.50	2.89

Sample	ID	Orientation	Depth (top)	Formation	Density	Load	VS2	Load	VS2	Load	VS2	Load	VS2	Load	VS2	AVG VS2 5-7 Mpa	AVG VS2 9-10 Mpa
			m		g/cm3	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	km/s	km/s
1	1A	45.00	5.18	Rastrites	2.64												
	1B	Vertical		Rastrites	2.58	5	2.09									2.09	
6	6A	45.00	24.80	Rastrites	2.55	5	2.63	5	2.62	10	2.59	10	2.58			2.62	2.58
	6B	Vertical		Rastrites	2.53	5	1.50			10	1.63					1.50	1.63
	6C	Horizontal		Rastrites	2.56	5	2.42	5	2.40	10	2.38	10	2.38			2.41	2.38
8	8A	45.00	35.00	Rastrites	2.56	5	1.81			10	1.42					1.81	1.42
	8B	Vertical		Rastrites	2.62	5	1.88	5	2.22	10	1.94	10	1.94			2.05	1.94
	8C	Horizontal		Rastrites	2.61	5	2.74	5	2.57	5	3.02			10	1.75	2.77	1.75
11	11A	45	44.90	Rastrites	2.63	5	3.63	5	3.63	10	3.25	10	3.25			3.63	3.25
	11B	Vertical		Rastrites	2.63	5	1.98	5	1.99	10	1.99	10	2.00			1.99	2.00
	11C	Horizontal		Rastrites	2.61	5	2.08									2.08	
	11D	Horizontal		Rastrites	2.61	5	1.71									1.71	
12	12A	45	50.82	Rastrites	2.46	3	1.73									1.73	
	12B	Vertical		Rastrites	2.53	5	1.51			10	1.58					1.51	1.58
	12C	Horizontal		Rastrites	2.51	5	2.04			10	2.46					2.04	2.46
13	13	Vertical	56.52	Rastrites	2.59	5	1.48			10	1.54					1.48	1.54
14	14A	45	61.30	Lindegård	2.65												
	14B	Vertical		Lindegård	2.62					5	2.34	10	2.27	10	2.27	2.34	2.27
	14C	Horizontal		Lindegård	2.51			5	2.14			10	2.21			2.14	2.21
15	15A	45	69.39	Lindegård	2.71	5	3.31	5	3.31	10	3.34	10	3.34			3.31	3.34
	15B	Vertical		Lindegård	2.68	5	2.05	5	2.06	10	2.08	10	2.08			2.06	2.08
	15C	Horizontal		Lindegård	2.65	5	2.55	5	1.82	10	2.55					2.19	2.55

Sample	ID	Orientation	Depth (top)	Formation	Density	Load	VS2	Load	VS2	Load	VS2	Load	VS2	Load	VS2	AVG VS2 5-7 Mpa	AVG VS2 9-10 Mpa
			m		g/cm3	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	km/s	km/s
16	16A	45	74.90	Dicellograptus	2.29	5	2.43	5	2.43							2.43	
	16B	45		Dicellograptus	2.50			5	1.35							1.35	
	16C	Vertical		Dicellograptus	2.55			5	2.00			10	1.73			2.00	1.73
	16D	Horizontal		Dicellograptus	2.45	5	2.63	5	2.63							2.63	
18	18A	45	80.40	Dicellograptus	2.46	5	2.48	5	2.50	9	2.50	9	2.50			2.49	2.50
	18B	Vertical		Dicellograptus	2.52	5	1.69	5	1.69	10	1.70	10	1.70			1.69	1.70
	18C	Horizontal		Dicellograptus	2.48			5	1.62			10	1.46			1.62	1.46
20	20A	45	93.40	Dicellograptus	2.60	7	3.16	7	3.16	10	3.14	10	2.64			3.16	2.89
	20C	Horizontal		Dicellograptus	2.58			5	2.35			10	2.35			2.35	2.35
23	23B	Vertical	101.50	Alum	2.31	5	1.18	5	1.18	10	1.17					1.18	1.17
	23C	Horizontal		Alum	2.30			7	2.43			10	2.97			2.43	2.97
25	25A	45	105.80	Alum	2.44												
	25B	Vertical		Alum	2.50	5	1.30	5	1.29	10	1.58	10	1.58			1.30	1.58
26	26A	45	110.90	Alum	2.42	5	1.19	5	1.50	10	1.52	10	1.52			1.35	1.52
	26B	Vertical		Alum	2.41			5	1.73			10	1.82			1.73	1.82
	26C	Horizontal		Alum	2.55	5	2.59	5	2.59	10	2.94	10	2.94			2.59	2.94

Sample	ID	Orientation	Depth (top)	Formation	Density	Load	VS2	Load	VS2	Load	VS2	Load	VS2	Load	VS2	AVG VS2 5-7 Mpa	AVG VS2 9-10 Mpa
			m		g/cm3	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	Mpa	km/s	km/s	km/s
29	29A	45	116.78	Alum	2.58	5	2.53	5	2.53	10	2.53	10	2.54			2.53	2.53
	29B	Vertical		Alum	2.58	5	1.65	5	1.69	10	1.67	10	1.69			1.67	1.68
	29C	Horizontal		Alum	2.55	6	2.72	6	2.74	10	2.44	10	2.44			2.73	2.44
30	30A	45		Alum	2.59												
	30C	Horizontal	119.80	Alum	2.59	5	2.50	5	2.30	10	3.05	10	3.08			2.40	3.06