DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2008/63

Pumping power: Rock quality of limestone at Stevns & Rørdal

Christian Knudsen & Peter Roll Jakobsen

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

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G E U S

Content

1 Introduction

This report is prepared by GEUS for DONG Energy Power. GEUS has used the following subcontractors: GEO for unconfined compression strength analysis, Sveriges Geologiske Undersøgelse (SGU) for information concerning the bedrock in southern Sweden and Nick Barton for QA of the Q-index work and the report.

Objectives

The overall aim with the project is to locate potential sites for establishing “pumping power (PP)” in Denmark (and immediate surroundings).

The main objective with the work reported here is to investigate the rock quality of the chalk at two sites in Denmark. The purpose is to deliver data for engineering geological calculations and considerations by Norplan.

GEUS has been asked to perform a brief geological survey of possibilities of establishing PP in Southern Sweden. This through its sister agency in Sweden – Sveriges Geologiske Undersøgelse (SGU).

Apart from this GEUS has also been asked to suggest a plan for further action.

The present investigation has focussed on the rock quality in two drill-holes/cores. The study has not focussed on the presence or absence of major tectonic features and fractures in the area that may affect the viability of excavating a cavern in the chalk. Further, no hydrogeological considerations have been included.

Background

Naturally fluctuating energy sources such as wind- and other (wave- tidal- and sun-energy) is projected to contribute with an increasing fraction of the Danish energy production, and their integration into the electrical power system/grid will become more and more important.

The planned increase in wind energy production in Denmark may lead to a situation where there is not enough capacity to cover the demand for electricity in periods with little or no wind. There may also occur situations where there will be overproduction/-flow in the electricity system.

When the contribution from wind energy increases, the main challenges for the electricity system will be:

- Generation of power when there is no wind
- Handling of fluctuations in power demand and use
- Full use of the electricity production in periods with high wind power production.
- Prediction of when electrical power is available

Due to the nature of the fluctuating energy sources there is a strong need for efficient electricity storage facilities/technologies. An efficient electricity power storage facility can store the power when there is overproduction of wind energy and deliver the electricity when the wind does not blow sufficiently relative to the electricity consumption.

There are many different electricity storage technologies among which the most widespread is “pumping power” with more than 70 GW installed worldwide. The principle is that there are two reservoirs – an upper and a lower and in times of excess energy water is pumped from the lower to the upper reservoir. When the power is needed the water is then let through a turbine from the upper to the lower reservoir.

Initial investigations indicate that pumping power is the most efficient way to store large quantities of power with high energy conversion efficiency (ca 80%).

In Denmark there is a lack of natural topography to make the above described model possible on the surface. Accordingly, the present investigation is part of an evaluation of the viability of making an underground lower reservoir. As an upper reservoir either an artificial lake or the sea can be used.

The target depth is 300 to 500 m and the target volume is ca. 1 mill m^3.

General geological considerations

To be able to make a cavern with the sufficient volume at a depth of 300 to 500 m, the rock must have certain strength (ca. > 10 MPa). Basement rocks such as gneiss and granite fulfil this criterion, but the depth to the basement rocks in Denmark is generally more that 1 km, and only at Bornholm they are located at a depth where a cavern is within the target depth. Basement rocks are located near surface in southern Sweden, and a brief review of the occurrence of basement rocks and their properties is given in section 4.

Limestone is the only lithology in near surface deposits in Denmark that is likely to have properties that match what is needed for making a cavern at the target depth 300 – 500 m.

Tunnelling has been performed in the København Limestone in the Copenhagen area e.g. related to the Copenhagen Metro, and there is extensive experience with the rock mechanical properties of this unit. The strength of this limestone unit is very variable ranging from 1 to 100 MPa (Knudsen et al 1995).

The limestone is rather soft where it occurs as chalk, near the surface in Denmark, but experience from the North sea indicates that the chalk becomes indurated at depth (Fabricius et al., 2008). The Limestone occurs near the surface in parts of Denmark (Fig. 1), and it forms very thick deposits in the Danish subsurface (Fig. 2). Accordingly, the focus of this investigation has been on the limestone.

The main part of the limestone consists of a very fine-grained porous rock called chalk. This rock is mainly deposited during the Upper Cretaceous. The chalk consists mainly of coccoliths which was calcium carbonate shell fragments. Apart from the calcium carbonate shell fragments, the chalk contains 5 to 10 % flint. At the end of the Cretaceous (65 million years ago) the character of the limestone changed to a slightly coarser unit called "bryozoan limestone". This unit is generally slightly better lithified and it is 50 to 100 m thick. Over the bryozoan limestone, the ca. 50 m thick Copenhagen Limestone was deposited, which is the unit into which the Copenhagen Metro is excavated.

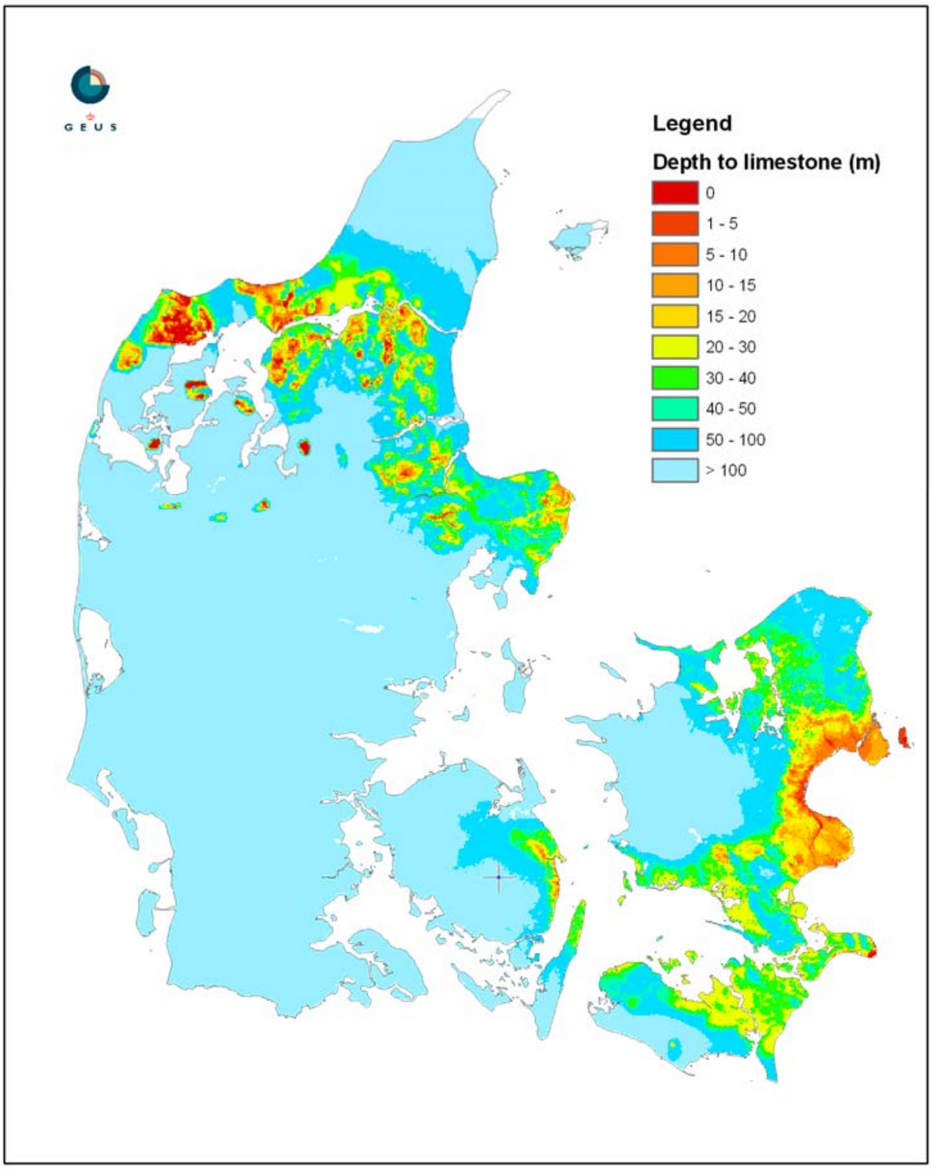


Figure 1 Depth to limestone.

2 Q-rating of drill core in chalk

Drillcore from two wells is described according to the Q system (Barton et al., 1992) and the detailed description by Peter Roll Jakobsen is attached as Appendix 1.

Only one fairly deep drillcore was available namely the Stevns-1 core, which has been made available by the Cretaceous Research Centre who obtained the core for scientific purposes (Stemmerik et al., 2006). To be able to compare chalk properties to other parts of Denmark, a 100 m long drillcore in chalk from Rørdal was also described and analysed. The location of the two cores described is shown on Fig. 2.

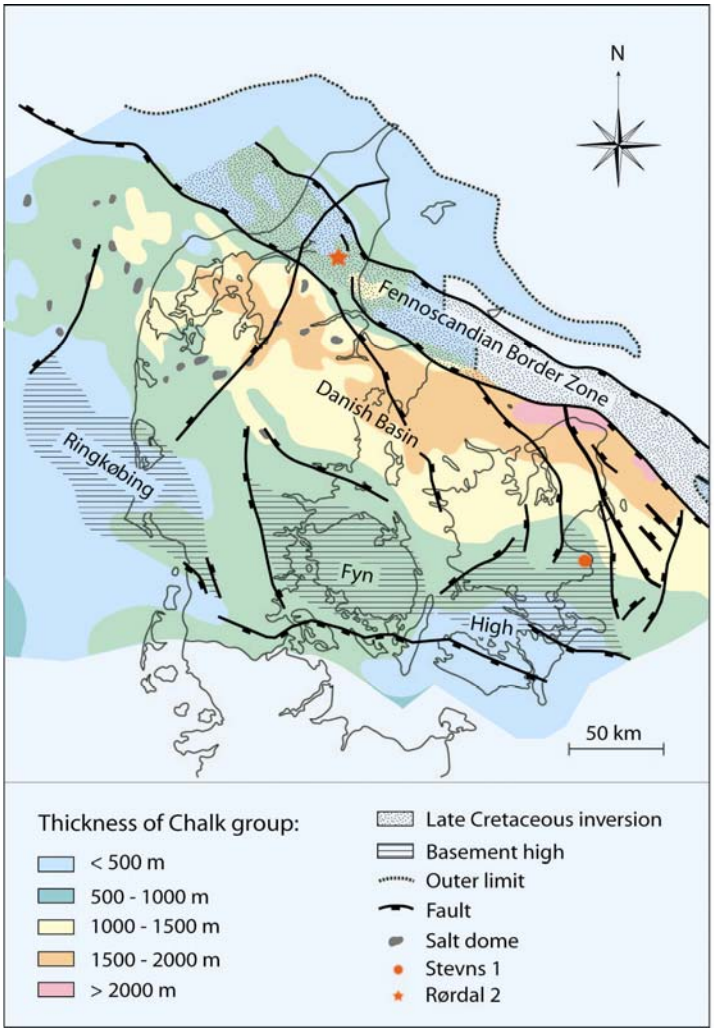
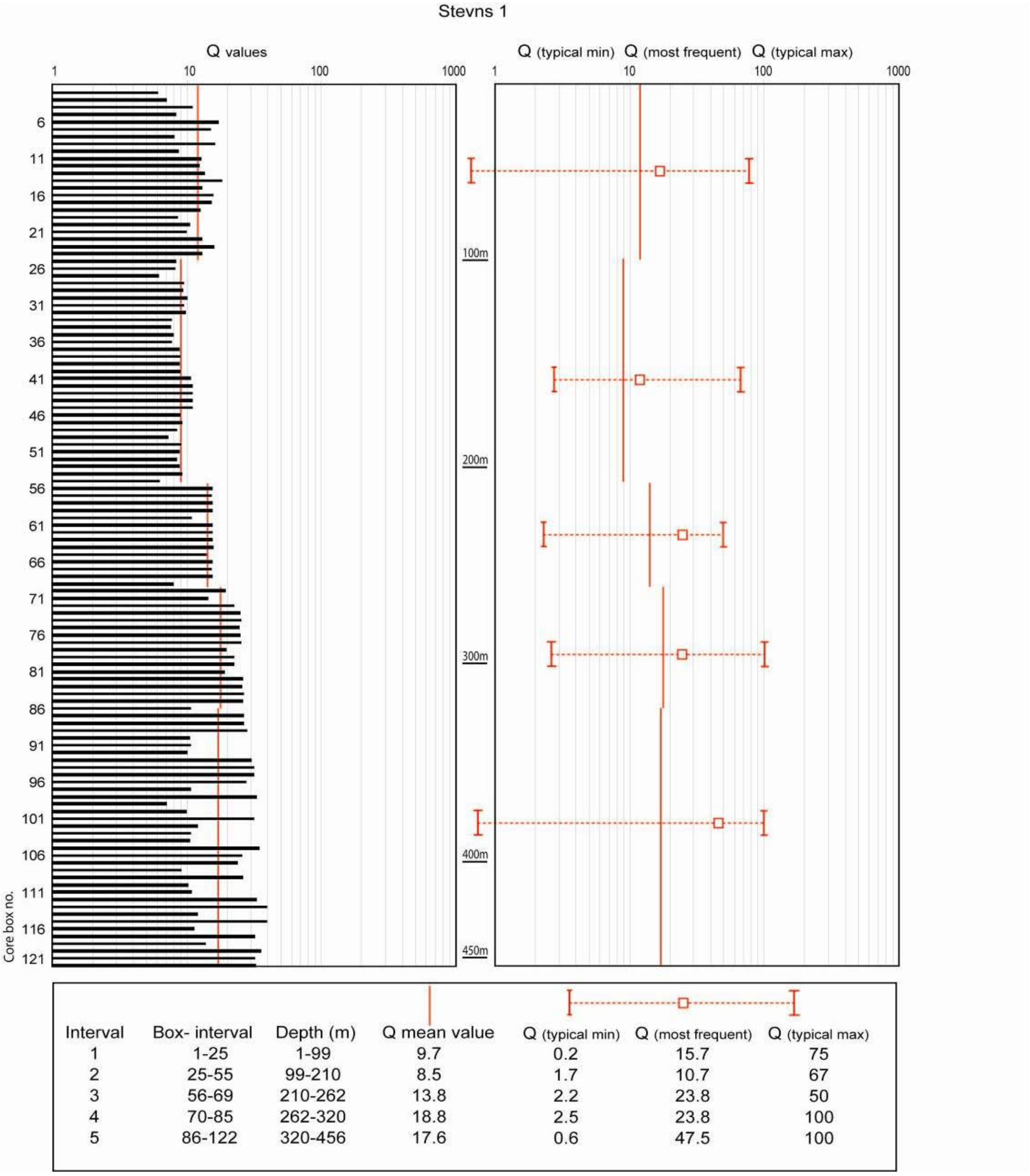


Figure 2. Thickness of the chalk group in the Danish Basin and major fault zones. The position of the Stevns 1 borehole and Rørdal 2 borehole are indicated.

The Rørdal 2 boring is situated within the Fennoscandian Border Zone, where faults are more frequent than outside the zone. Stevns 1 is situated on the Ringkøbing–Fyn High (Rosenbom & Jakobsen, 2005).

Stevns-1

The core consists of Cretaceous chalk, which in the uppermost 160 m contains layers of flint, gradually decreasing in frequency downwards. One horizontal joint-set is seen together with one or two steeply dipping joint sets. From outcrop in the area, four steep to vertical joint sets are known near surface. The general impression of the core is that the jointing is most intense at the top and decreases downwards. Two faults are observed in the core, and in both cases, the breccias were healed and filled with calcite. The degree of induration increases downwards and the Q rates obtained increase stepwise downwards (Fig 3). However, the presence of marl layers in the chalk in the interval between ca 300 and 456 m are considered to be weakness zones which reduces the Q-values in intervals with marl layers.



Interval	Box- interval	Depth (m)	Q mean value	Q (typical min)	Q (most frequent)	Q (typical max)
1	1-25	1-99	9.7	0.2	15.7	75
2	25-55	99-210	8.5	1.7	10.7	67
3	56-69	210-262	13.8	2.2	23.8	50
4	70-85	262-320	18.8	2.5	23.8	100
5	86-122	320-456	17.6	0.6	47.5	100

Figure 3 Q values in the Stevns-1 well.

In the core description (Appendix 1) it is noticed that there are a number of marly layers mainly in the interval between 310 and 440 m below surface. This is also reflected in the gamma log (Fig. 10), with the highest amount of clay rich material between 310 and 380 m. The marly layers must be considered as weak zones, which leads to a large span of the assessed Q values.

Rørdal-2

This core also consists of Cretaceous chalk. The uppermost 34 m of the core was crushed during drilling. Q rating was performed from 34 to 102 m, and the Q rates obtained are comparable to the values obtained from the similar depth interval in the Stevns-1 well. The core contains flint but no marly layers were observed.

One horizontal joint-set was observed together with two steep to vertical. However, it is likely that there are three steep to vertical joint-sets as is the case at Stevns.

3 Porosity, permeability, chemistry and rock strength in chalk

Porosity, permeability, chemical composition and unconfined compression strength (UCS) has been measured in 20 samples from Stevns and 10 samples from Rørdal. The plugs were taken by GEUS parallel to the drillcore (vertically). Porosity and permeability measurements were performed at GEUS. The Unconfined Compression Strength (UCS) testing was carried out at GEO on dry air samples with approximately 25 mm diameter and 50 mm long. The results are tabulated in Table 1.

Table 1 Test results.

Sample	Depth m	Porosity (%)	Permeability (mD)	Grain density (g/cm3)	Dry density (g/cm3)	Compression Strength (MPa)	Young's modulus (GPa)
Stevns 1	10	37,2	10,9	2,698	1,69	11,9	2,58
Stevns 2	35	48,4	7,7	2,708	1,40	7,2	2,39
Stevns 3	70	44,0	6,0	2,698	1,51	4,8	1,14
Stevns 4	100	42,6	7,4	2,706	1,56	7,4	1,73
Stevns 5	130	42,9	4,8	2,707	1,54	5,8	1,29
Stevns 6	161	41,2	4,0	2,709	1,59	4,8	1,28
Stevns 7	190	41,6	4,1	2,698	1,57	8,4	1,81
Stevns 8	214	39,2	2,6	2,707	1,65	8,8	1,84
Stevns 9	243	38,6	2,5	2,702	1,66	7,4	1,25
Stevns 10	272	40,0	2,9	2,706	1,62	9,0	2,01
Stevns 11	301	37,8	2,3	2,706	1,68	14,2	3,22
Stevns 12	315	29,6	0,7	2,707	1,90	10,9	2,25
Stevns 13	330	30,3	0,9	2,697	1,87	20,6	2,86
Stevns 14	350	33,5	1,4	2,705	1,80	11,9	1,59
Stevns 15	370	31,9	0,9	2,697	1,84	27,8	4,05
Stevns 16	390	29,7	0,9	2,705	1,90	25,9	3,88
Stevns 17	410	27,3	1,0	2,715	1,98	30,9	4,83
Stevns 18	420	26,2	0,7	2,703	2,00	36,0	5,28
Stevns 19	435	31,9	2,5	2,699	1,83	14,5	2,39
Stevns 20	450	30,7	1,2	2,699	1,87	21,3	3,98
Rørdal 1	11,6	41,84	2,7	2,65	1,53	10,1	1,57
Rørdal 2	19,65	43,09	4,5	2,664	1,52	8,5	1,16
Rørdal 3	29,78	45,62	6,7	2,692	1,45	5,0	0,90
Rørdal 4	40,9	46,43	8,4	2,672	1,43	5,3	0,80
Rørdal 5	50,3	46,03	6,1	2,673	1,45	5,3	0,72
Rørdal 6	60	42,22	4,2	2,677	1,54	6,9	0,82
Rørdal 7	70	46,28	6,2	2,676	1,44	5,9	0,98
Rørdal 8	80	46,38	7,8	2,678	1,44	5,9	0,64
Rørdal 9	90	46,92	5,4	2,673	1,41	5,2	1,09
Rørdal 10	100	43,57	3,9	2,674	1,5	4,9	0,52

There is a substantial variation in the porosity in the chalk due to variable degree of cementation of the pore space. This has an effect on the bulk density of the rock increasing with the degree of cement in the pore space (Fig. 4). There is also a fairly good relationship between the porosity and the (matrix) permeability in the chalk (Fig. 5).

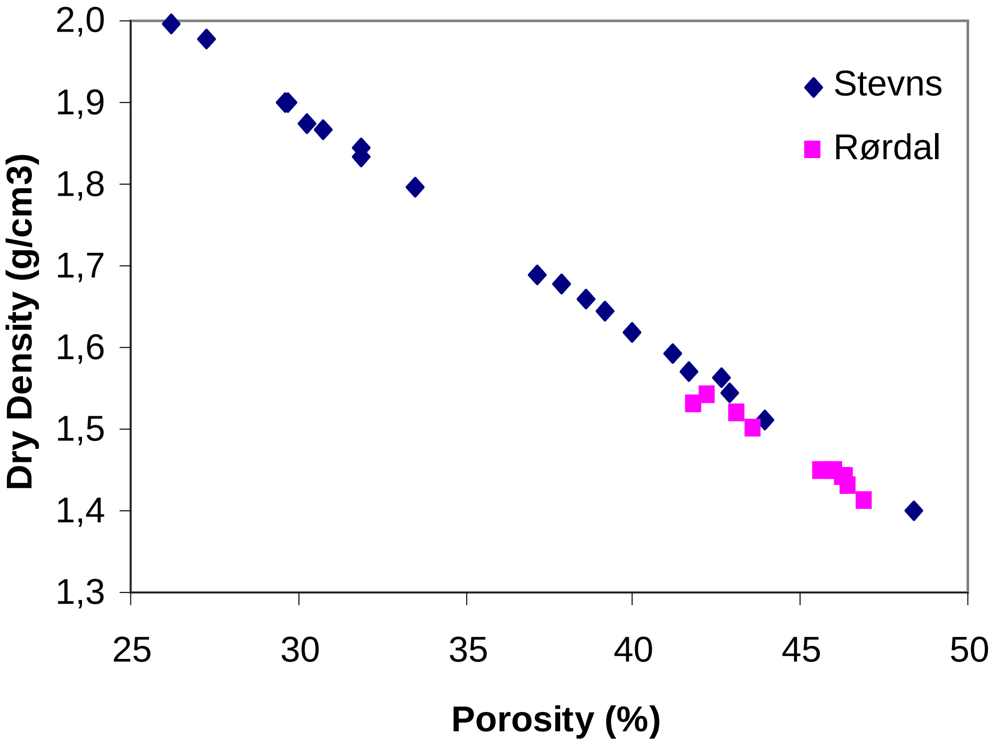


Figure 4 Bulk density versus porosity.

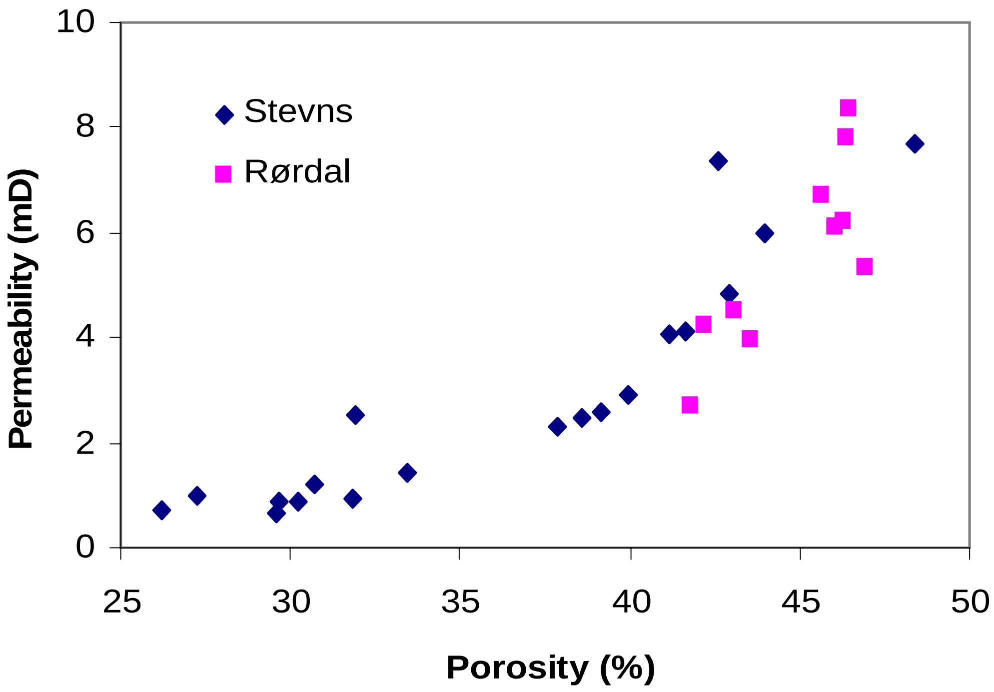


Figure 5 Permeability versus porosity.

At depth the core in Stevs-1 becomes more indurated (H3) and is also reflected in the decreasing porosity (Fig. 6) and permeability (Fig. 7).

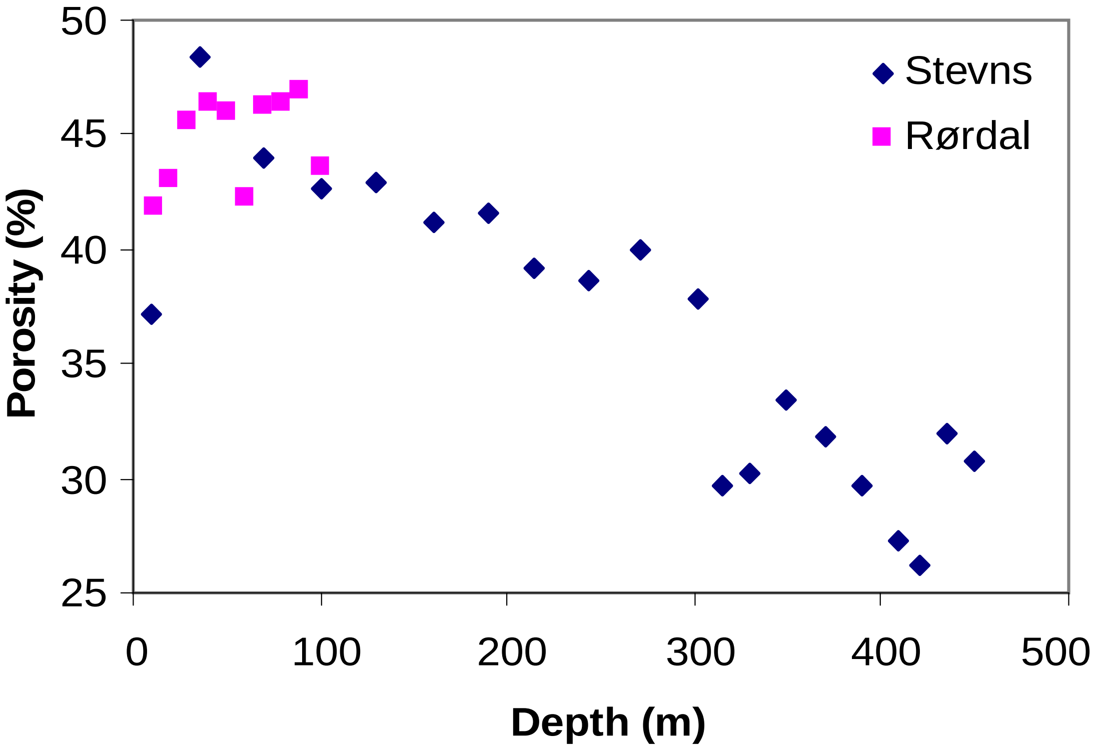


Figure 6 Porosity versus depth.

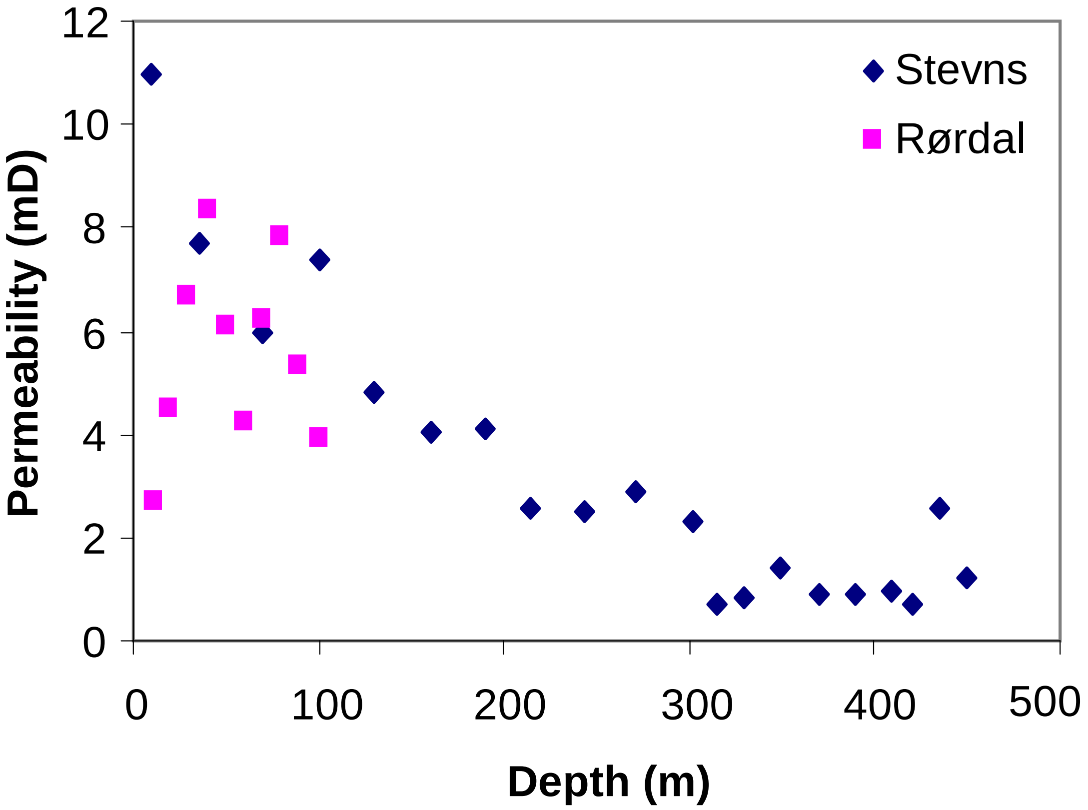


Figure 7 Permeability versus depth.

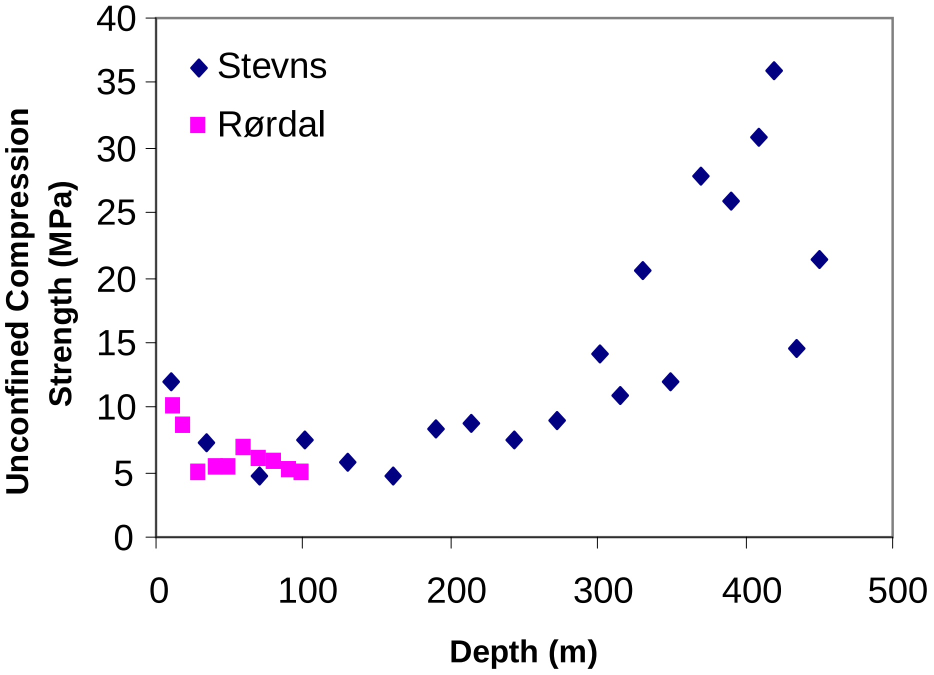


Figure 8 Unconfined Compression Strength versus depth.

As can be seen on Fig. 8, there is an increase in the strength of the chalk towards depth. This is also reflected in the well logs from the drill hole (Fig. 10) where the p-wave velocity increases towards depth.

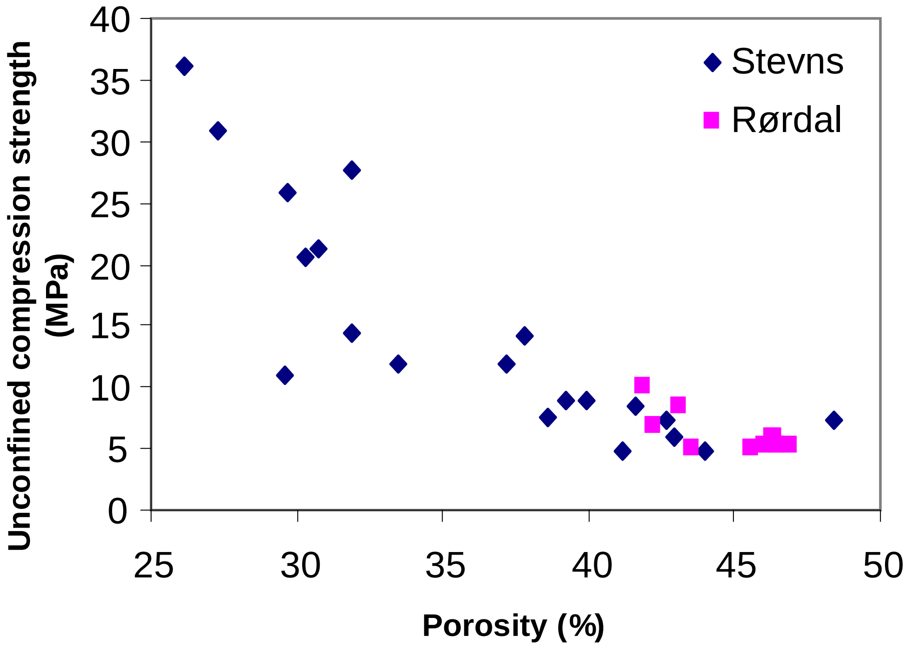


Figure 9 Unconfined Compression Strength versus porosity

As can be seen on Fig. 9, there is a relationship between the porosity and the strength of the rock. This is because the less porous rocks are better cemented and accordingly more coherent and strong. There is one sample that falls below the line, which may be due to elevated clay (marl) content.

The chalk has a very high porosity close to the surface in Denmark as a general rule. Exceptions from this are seen e.g. in the Copenhagen Limestone of Danian age, where very early diagenesis has caused cementation of the chalk (Knudsen et al. 1994 and Knudsen et al. 1995). Intense early diagenesis is rarely seen in Cretaceous chalk onshore Denmark and this is not considered a likely process in the Stevns-1 drill-core. The observed decrease in the porosity is likely to be caused by one or most likely by both of the following factors.

As can be seen in Table 1, there is an increase in strength at 100 m coinciding with an increase in gamma ray activity (Fig. 10). This effect can also be seen when comparing the gamma and the porosity logs, where there is a clear relationship between decreasing porosity and increasing gamma. The gamma ray activity is mainly generated by radiation from K in clay in the chalk. This indicates that there is increased compaction/cementation in layers with elevated clay content. A similar relationship is seen where the clay increases from 260 m and downwards. The clay content may vary laterally for a given stratigraphical horizon. The clay content is a primary feature resulting from the influx of clay into the sea when the chalk was formed. This means that the observed increase in strength with depth may vary laterally in Denmark.

However, the porosity is lower in the deep part of the drillcore for rocks with similar clay content at more shallow levels. This indicates that there is also a depth related increase in the porosity reduction. This is as expected from experience e.g. from the North Sea. The chalk at Stevns has been buried under at least 0,5 km of sediments and the elevated strength at 300 m depth is as could be expected as the total thickness of overburden approaches ca. 1 km.

The porosity of the chalk in Rørdal is similar to or slightly higher than at similar levels at Stevns and the Q-values and strength values are also similar. It is not possible to project the results from Stevns to the Rørdal – North Jylland area. However, it is considered likely that the clay content will increase slightly downwards in Jylland as is seen in Stevns. Further, North-western Jylland has also been buried below more than 500 m of sediments, and it is considered likely that the diagenesis caused by loading found at Stevns is also to be found in North-western Jylland.

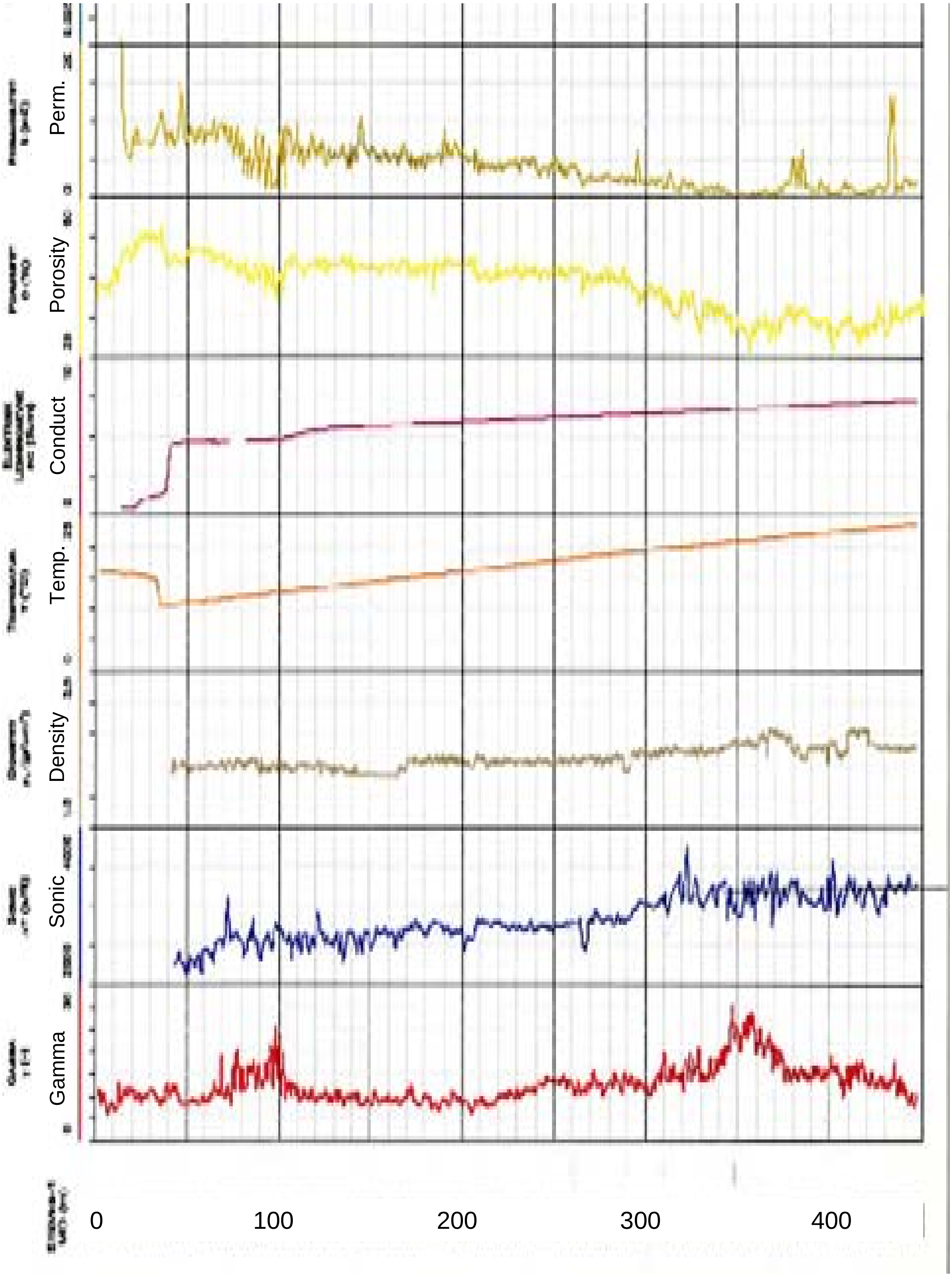


Figure 10 Well logs from the Stevns-1 well (Stemmerik et. al. 2006).

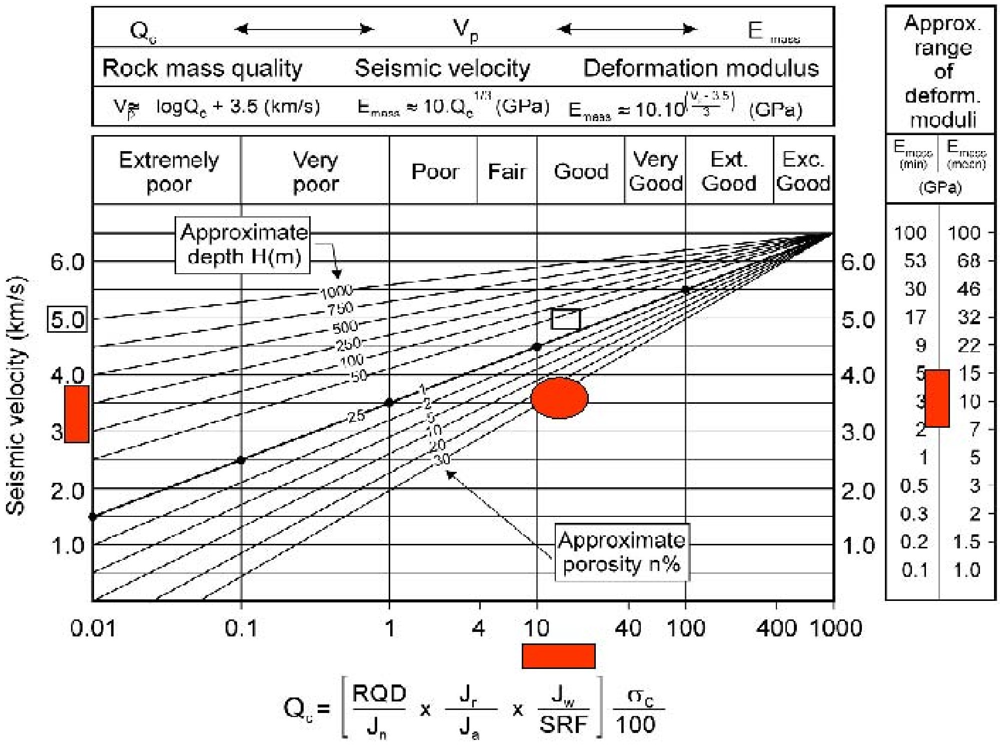


Figure 11. The integration of velocity, Q-value, porosity, strength and depth shows sensible correlation to the results obtained, when velocity reaches about 4 km/s for the limestone at greater depth, lower porosity and with increased UCS. Barton (2006).

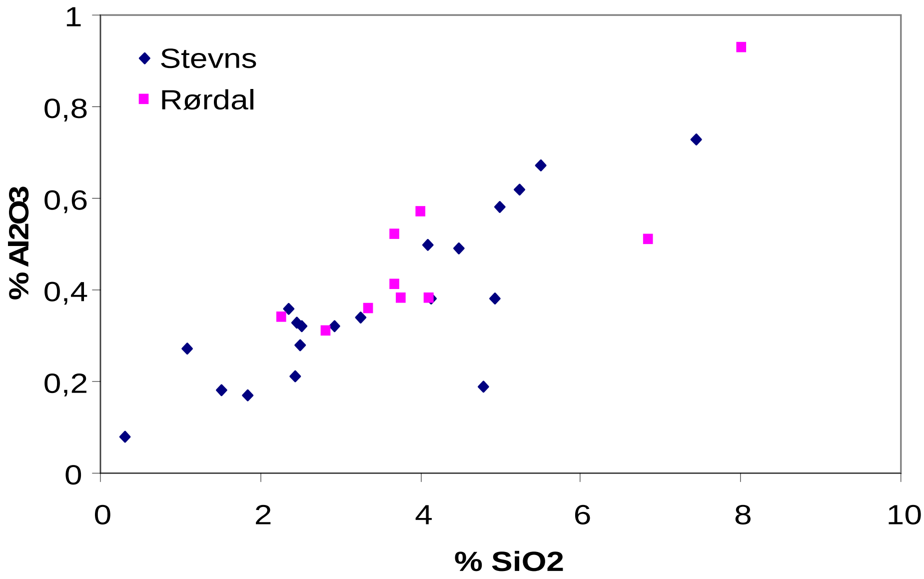


Figure 12 Al_2O_3 versus SiO_2.

The relationship between the content of Al_2O_3 and SiO_2 seen on Fig. 12 is at least partly caused by the fact that both elements are found in clay minerals.

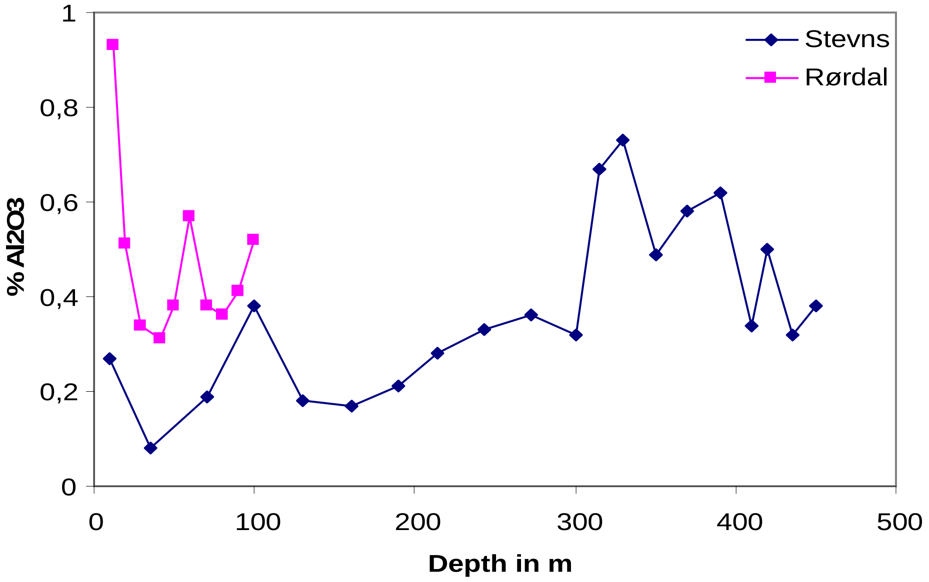


Figure 13 Al_2O_3 versus depth.

It is seen (Fig. 13) that at Stevns, there is a peak in the aluminium content caused by increased clay content at ca. 80 to 100 m depth and again increased clay content below 300 m. The graph is very similar to the gamma ray curve (Fig. 11) reflecting the fact that the natural gamma radiation is caused by potassium (K) which is also located in the clay minerals.

The Al (clay) content in Rørdal near surface is higher as compared to Stevns at surface. This may be because the chalk at Rørdal belongs to a ca. 100 m deeper stratigraphic level as compared to Stevns (Niels Schousboe pers. comm.).

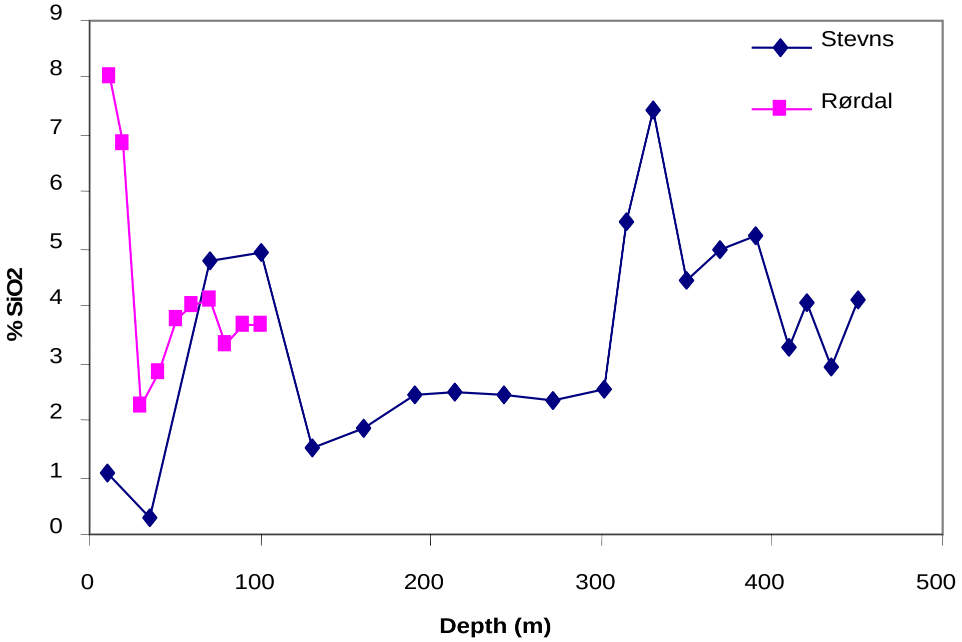


Figure 14 SiO_2 versus depth.

4 Possibilities in southern Sweden

In southern Sweden, there are well known outcrops of basement rocks e.g. on Kullen, Bjäre Halvön, Söderåsen and Romeleåsen. These areas consist of tectonic blocks that have been lifted up due to faulting. The basement rocks consist of a variety of rock types from granites and syenites to granitic gneisses, mica schists and amphibolites. These rocks are cut by a large number of basaltic dykes/diabase. No tests have been performed on these rocks, but they are in general easily strong enough as such to built caverns in the target depth of 300 to 500m.

Table 2

Rock type	Proportion (%)
Sandstone	10
Diabase	3
Syenite	4
Granite	15
Granitic gneiss	15
Amphibolite	8
Gneiss	45

Rock types in Romeleåsen (Naturvårdsenheten, 1988).

Maps prepared by SGU showing the thickness of Quaternary overburden, and areas where crystalline basement rocks, Cambrian and Ordovician rocks, Jurassic and Cretaceous rocks and major tectonic elements are included as Appendix 2.

Based on the maps, it can be concluded that there are many areas where the crystalline basement occur with less than 15 m of Quaternary overburden and accordingly are accessible for construction of vertical shafts leading to caverns at target depth.

The main problems concerning building caverns in southern Sweden is faulting and fracturing of the rocks tied to tectonic events. This has been the case during tunnelling in Hallandsåsen. To be able to locate areas where the density of faults and fractures is low enough for construction of a cavern, it will be necessary to conduct detailed geological, geophysical and geotechnical investigations.

Further investigations could be divided into three phases:

1. Geological mapping of favourable sites where the basement outcrop at the surface. This to test if it is possible to locate areas where the fracture density is low enough to allow for construction of a cavern.
2. Shallow drilling, ground penetrating radar, refraction seismics and cross-hole seismic and other geophysical surveys at favourable sites to test the 3D distribution of faults and fractures.
3. Drilling to target depth to test the rock quality and fracture distribution at a potential cavern site. The holes should preferntially be 10 to 20 deg. inclined from vertical orientation to intersect vertical and subvertical structures.

5 Conclusions

The chalk

The Q-rating performed by GEUS of the drillcore from Stevns-1 show that there is a general increase in rock quality towards depth. The values are above 10 below 210 m. However, frequent marly layers affects the rock quality locally below 300 m.

The general increase in Q-values with depth is accompanied by increasing strength of the rock so that the UCS is above 10 MPa for all rocks below 300 m and generally above 20 MPa in this interval. The observed increase in rock strength is likely to be tied to both the clay content and to the depth and diagenesis tied to the loading of the rock.

The general rock quality is evaluated to be suitable for excavating a cavern at a depth of 300 to 500 m at Stevns. There are however, 1 to 5 cm thick marly layers in the chalk. These layers are weaker than the surrounding rock. Further geotechnical considerations are needed to evaluate if this constitute a major problem for construction of a cavern at the target depth.

The porosity of the chalk in Rørdal is similar to or slightly higher than at similar levels at Stevns and the Q-values and strength values are also similar. It is not possible to project the results from Stevns to the Rørdal – North Jylland area. However, it is considered likely that the clay content will increase slightly downwards in Jylland as is seen in Stevns. Further, north-western Jylland has also been buried below more than 500 m of sediments, and it is considered likely that the diagenesis caused by loading found at Stevns is also to be found in north-western Jylland. This part of Denmark is located in or near the Fennoscandian Border Zone with tectonic activity. Salt domes are also frequent below the chalk. Accordingly, fractures and faults can be expected to be more frequent as compared to the Stevns area.

The results of the present investigation indicate that it is viable to continue investigations concerning establishing “pumping power” in Denmark.

South Sweden

There are many areas in southern Sweden where the crystalline basement occur with less than 15 m of Quaternary overburden and accordingly easy accessible for construction of caverns. The main problems concerning building a deep shaft and large caverns in southern Sweden is faulting and fracturing of the rocks tied to tectonic events. This has been the case during tunnelling in Hallandsåsen. To be able to locate areas where the density of faults and fractures is low enough for construction of a cavern, it will be necessary to conduct detailed geological, geophysical and geotechnical investigations.

6 Recommendations

The chalk

If a cavern is to be considered at Stevns, it is recommended to conduct

- More detailed testing of the rock properties at the target depth with a focus of the geotechnical properties of the marly horizons.
- A more detailed study of the logs available from the Stevs-1 well.
- Conduct a shallow seismic study of the area aiming at locating fault- and fracture-zones.
- Perform more drilling preferentially using inclined (10 to 20 deg.) holes to be able to get a better impression of the steeply dipping to vertical fracture systems.
- Describe and test the drillcore.

If the possibilities of excavating a cavern in north-western Jylland are to be tested, it is recommended to conduct::

- A study of available well and geophysical information aiming at locating the best area for further investigations, i.e. where the chalk is near surface and the risk of having major tectonic structures is low.
- Based on this, an area is selected for further studies.
- A shallow seismic survey should be conducted aiming at locating the area with the best chances of having low frequency of faults and fractures.
- Perform drilling preferentially using inclined holes to be able to get a better impression of the steeply dipping to vertical fracture systems.
- Describe and test the drillcore.

South Sweden

Further investigations could be divided into three phases:

1. Geological mapping of favourable sites where the basement crop out on the surface. This to test if it is possible to locate areas where the fracture density is low enough to allow for construction of a deep shaft and large caverns.
2. Shallow drilling, ground penetrating radar and other geophysical surveys (seismic refraction and crosshole seismics) at favourable sites to test the 3D distribution of faults and fractures.
3. Drilling to target depth to test the rock quality and fracture distribution at a potential cavern site.

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Appendix 1

Q-rating on the Stevns 1 Borehole (DGUnr 218.1338) and the Rørdal 2 Borehole (DGUnr 26.1925)

By Peter Roll Jacobsen, GEUS

Appendix 2

Crystalline rocks found less than 500 m below ground in Skåne

By Ulf Sivhed

Sveriges Geologiske Undersökning

Introduction

In order to quantify the rock mass conditions of the chalk in Denmark, the Q system has been applied amongst other methods. The result of the Q-rating is presented in this appendix.

Two borehole cores, drilled in chalk, were chosen for this purpose; the Stevns 1 core and the Rørdal 2 core (fig. 1). The Stevn 1 core was chosen as the boring is 456m deep, and the Rørdal core was chosen to get a regional picture of the rock stability of the chalk. The Rørdal 2 boring is situated within the Fennoscandian Border Zone, where faults are more frequent than outside the zone. Stevns 1 is situated on the Ringkøbing –Fyn High. This terrain is tectonically more stable, but the origin of the steep/vertical joints in the chalk on Stevns are interpreted to be of tectonic origin (Rosenbom & Jakobsen, 2005).

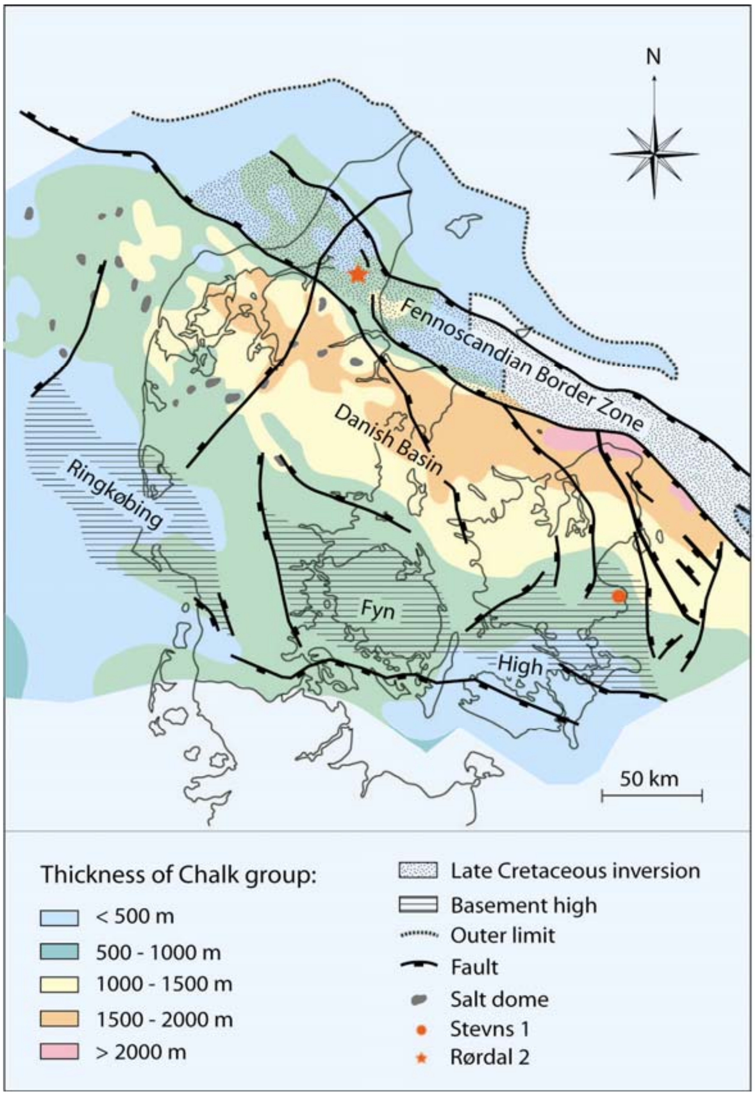


Figure 1. Thickness of the chalk group in the Danish Basin, and major faults, The position of the Stevns 1 borehole and Rørdal 2 borehole are indicated.

Method

Q-system

The Q system is an empirical method (Barton et al. 1974, Barton et al., 1992, Barton & Grimstad, 1994a) based on the RQD method of describing drill core (Deere et al., 1967) and five additional parameters, which modify the RQD-value for the number of joint sets, loint roughness and alteration (filling), the amount of water and various features associated with high stress, squeezing and swelling.

The Q-value is expressed by:

Q = RQD/Jn X Jr/Ja X Jw/SRF

In combination the parameters represent

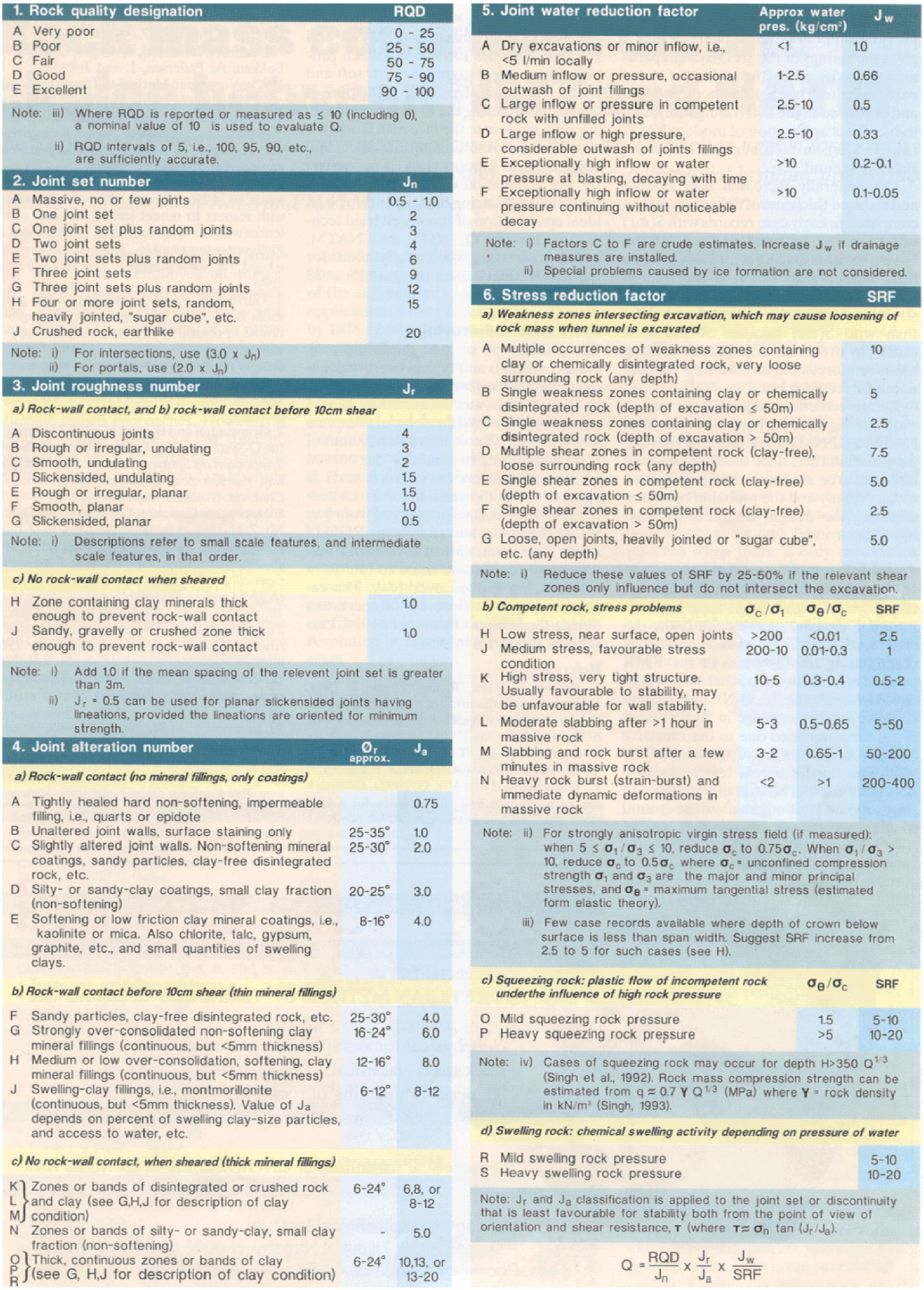
1. The relative Block size, given as a quotient
   RQD/Jn = Degree of jointing/number of joint sets

2. The inter-block shear strength
   Jr/Ja = joint roughness/joint alteration or filling

3. The active stress
   Jw/SRF = water pressure or leakage/rock stress conditions

Q-Parameters are listed in figure 2.

The Q system tunnel and cavern design chart is used to configure the support design in tunnels and caverns. In the chart the rock classes range from exceptionally poor to exceptionally good (Fig. 3).



1. Rock quality designation		RQD
A	Very poor	0 - 25
B	Poor	25 - 50
C	Fair	50 - 75
D	Good	75 - 90
E	Excellent	90 - 100

Note: iii) Where RQD is reported or measured as ≤ 10 (including 0), a nominal value of 10 is used to evaluate Q.

ii) RQD intervals of 5, i.e., 100, 95, 90, etc., are sufficiently accurate.

2. Joint set number		J_n
A	Massive, no or few joints	0.5 - 1.0
B	One joint set	2
C	One joint set plus random joints	3
D	Two joint sets	4
E	Two joint sets plus random joints	6
F	Three joint sets	9
G	Three joint sets plus random joints	12
H	Four or more joint sets, random, heavily jointed, "sugar cube", etc.	15
J	Crushed rock, earthlike	20

Note: i) For intersections, use ($3.0 \times J_n$)

ii) For portals, use ($2.0 \times J_n$)

3. Joint roughness number		J_r
a) Rock-wall contact, and b) rock-wall contact before 10cm shear		
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickensided, planar	0.5

Note: i) Descriptions refer to small scale features, and intermediate scale features, in that order.

c) No rock-wall contact when sheared		
H	Zone containing clay minerals thick enough to prevent rock-wall contact	1.0
J	Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact	1.0

Note: i) Add 1.0 if the mean spacing of the relevent joint set is greater than 3m.

ii) J_r = 0.5 can be used for planar slickensided joints having lineations, provided the lineations are oriented for minimum strength.

4. Joint alteration number		$Ø_r$ approx.	J_a
a) Rock-wall contact (no mineral fillings, only coatings)			
A	Tightly healed hard non-softening, impermeable filling, i.e., quarts or epidote		0.75
B	Unaltered joint walls, surface staining only	25-35°	1.0
C	Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	25-30°	2.0
D	Silty- or sandy-clay coatings, small clay fraction (non-softening)	20-25°	3.0
E	Softening or low friction clay mineral coatings, i.e., kaolinite or mica. Also chlorite, talc, gypsum, graphite, etc., and small quantities of swelling clays.	8-16°	4.0
b) Rock-wall contact before 10cm shear (thin mineral fillings)			
F	Sandy particles, clay-free disintegrated rock, etc.	25-30°	4.0
G	Strongly over-consolidated non-softening clay mineral fillings (continuous, but <5mm thickness)	16-24°	6.0
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, but <5mm thickness)	12-16°	8.0
J	Swelling-clay fillings, i.e., montmorillonite (continuous, but <5mm thickness). Value of J_a depends on percent of swelling clay-size particles, and access to water, etc.	6-12°	8-12
c) No rock-wall contact, when sheared (thick mineral fillings)			
K L M	Zones or bands of disintegrated or crushed rock and clay (see G,H,J for description of clay condition)	6-24°	6,8, or 8-12
N	Zones or bands of silty- or sandy-clay, small clay fraction (non-softening)	-	5.0
O P R	Thick, continuous zones or bands of clay (see G, H,J for description of clay condition)	6-24°	10,13, or 13-20

5. Joint water reduction factor		Approx water pres. (kg/cm²)	J_w
A	Dry excavations or minor inflow, i.e., <5 l/min locally	<1	1.0
B	Medium inflow or pressure, occasional outwash of joint fillings	1-2.5	0.66
C	Large inflow or pressure in competent rock with unfilled joints	2.5-10	0.5
D	Large inflow or high pressure, considerable outwash of joints fillings	2.5-10	0.33
E	Exceptionally high inflow or water pressure at blasting, decaying with time	>10	0.2-0.1
F	Exceptionally high inflow or water pressure continuing without noticeable decay	>10	0.1-0.05

Note: i) Factors C to F are crude estimates. Increase J_w if drainage measures are installed.

ii) Special problems caused by ice formation are not considered.

6. Stress reduction factor		SRF
a) Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated		
A	Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock (any depth)	10
B	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation ≤ 50m)	5
C	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation > 50m)	2.5
D	Multiple shear zones in competent rock (clay-free), loose surrounding rock (any depth)	7.5
E	Single shear zones in competent rock (clay-free) (depth of excavation ≤ 50m)	5.0
F	Single shear zones in competent rock (clay-free) (depth of excavation > 50m)	2.5
G	Loose, open joints, heavily jointed or "sugar cube", etc. (any depth)	5.0

Note: i) Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation.

b) Competent rock, stress problems		σ_c/σ_1	σ_θ/σ_c	SRF
H	Low stress, near surface, open joints	>200	<0.01	2.5
J	Medium stress, favourable stress condition	200-10	0.01-0.3	1
K	High stress, very tight structure. Usually favourable to stability, may be unfavourable for wall stability.	10-5	0.3-0.4	0.5-2
L	Moderate slabbing after >1 hour in massive rock	5-3	0.5-0.65	5-50
M	Slabbing and rock burst after a few minutes in massive rock	3-2	0.65-1	50-200
N	Heavy rock burst (strain-burst) and immediate dynamic deformations in massive rock	<2	>1	200-400

Note: ii) For strongly anisotropic virgin stress field (if measured): when $5 \leq \sigma_1/\sigma_3 \leq 10$, reduce σ_c to $0.75\sigma_c$. When $\sigma_1/\sigma_3 > 10$, reduce σ_c to $0.5\sigma_c$ where σ_c = unconfined compression strength σ_1 and σ_3 are the major and minor principal stresses, and σ_θ = maximum tangential stress (estimated form elastic theory).

iii) Few case records available where depth of crown below surface is less than span width. Suggest SRF increase from 2.5 to 5 for such cases (see H).

c) Squeezing rock: plastic flow of incompetent rock underthe influence of high rock pressure		σ_θ/σ_c	SRF
O	Mild squeezing rock pressure	1.5	5-10
P	Heavy squeezing rock pressure	>5	10-20

Note: iv) Cases of squeezing rock may occur for depth $H>350\ Q^{1/3}$ (Singh et al., 1992). Rock mass compression strength can be estimated from $q \approx 0.7\ \gamma\ Q^{1/3}$ (MPa) where γ = rock density in kN/m³ (Singh, 1993).

d) Swelling rock: chemical swelling activity depending on pressure of water		
R	Mild swelling rock pressure	5-10
S	Heavy swelling rock pressure	10-20

Note: J_r and J_a classification is applied to the joint set or discontinuity that is least favourable for stability both from the point of view of orientation and shear resistance, τ (where $\tau \approx \sigma_n \tan(J_r/J_a)$.

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

Figure 2. Q-Parameters (from Barton & Grimstad, 1994b).

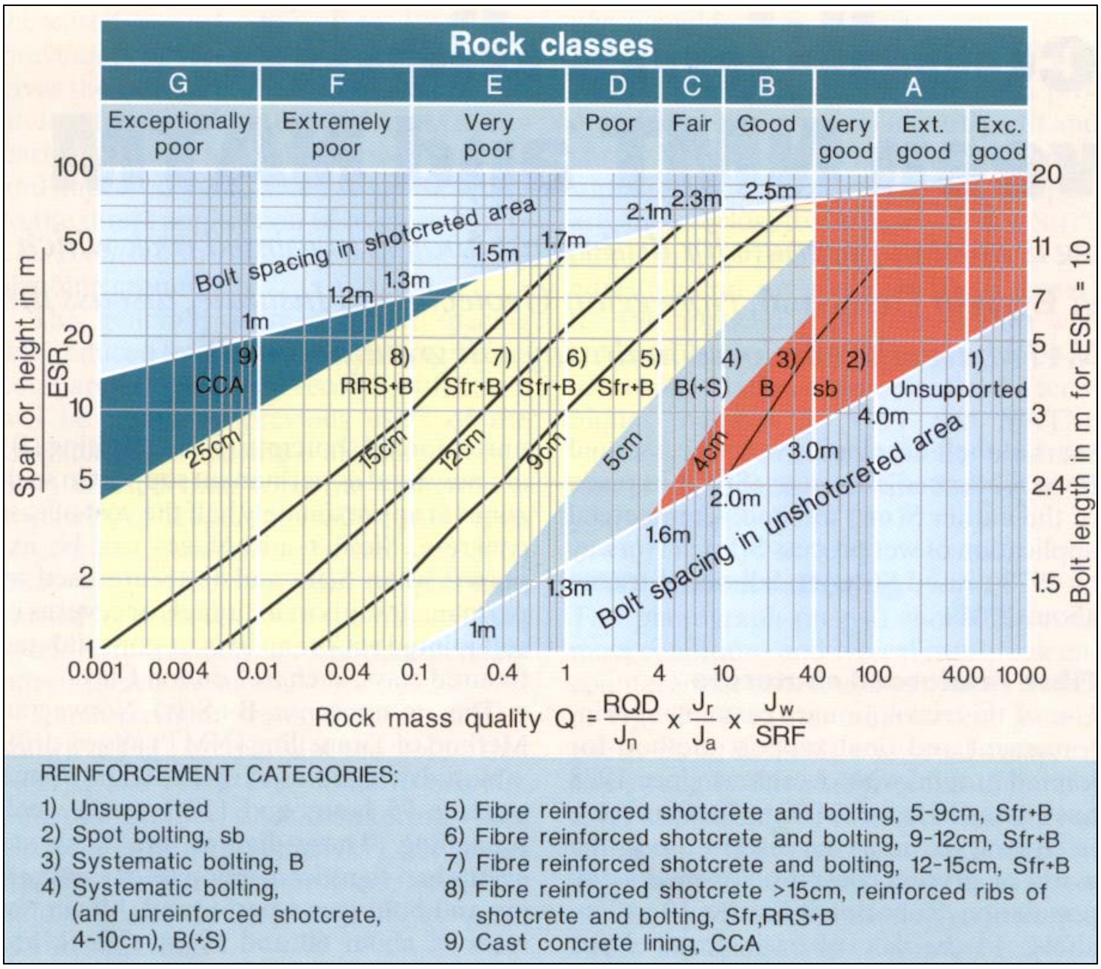


Figure 3. Q-system tunnel and cavern design chart (from Barton & Grimstad, 1994b)

Induration

The induration is assessed according to a 5 level scale according to Larsen et al. (1988).

H1: Loose material.

H2: Weakly indurated. The material can be scratched with a finger nail.

H3: Indurated. The material can not be scratched with a finger nail, but with knife.

H4: Strongly indurated. The material can be scrached with knife, but grains can not be loosened.

H5: Very strongly indurated. Material can not be scratched with knife.

Stevns 1

Quality of the core

The quality of the core is generally good (Figs. 4 and 5), but the core was subjected to slabbing/halving, which has caused additional breaking (Fig. 6). The core photos of the fresh core where very usefull to eliminate later breaking. Only the breaking seen on the core photos where examined to determine the RQD value of the core. When the core was examined it was dry.

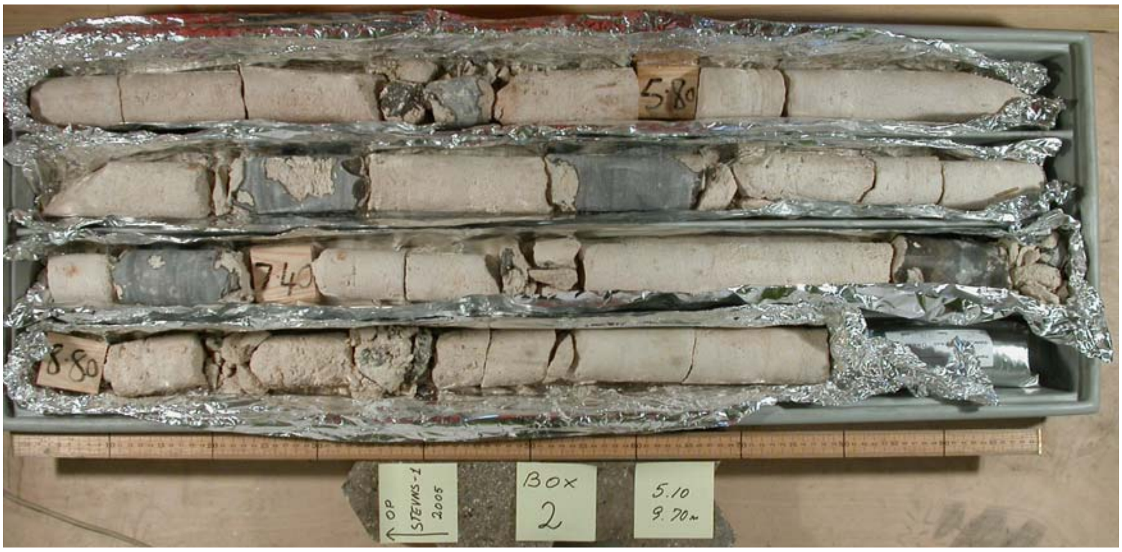


Figure 4. Core photo of the depth interval from 5.10 and 9.70m. Several flint layers occur and the RQD varies fron 25 to 85. Note that hardly any reflection is visible on the core due to the weak induration (H2) of the chalk.

Figure 5. Core photo of the depth interval from 424.40 and 428.17m. Several layers of marl occur. The RQD is 95 to 100. Note the shiny reflection visible on the core due to the higher degree of induration (H3) of the chalk.

Geology of the core

The core consists of chalk of cretaceous age. In the upper most 160 m of the core there are layers of flint. The flint gradually diminishes with depth and only few flint layers occur below 160 m. Layers of marl occur mainly in the interval between 310 m and 440 m below surface.

Joints

The chalk is jointed in various degrees. The Jointing is strongest in the upper part, and it decreases with depth. In a vertical borehole only few vertical or steep joints are seen in the core. Mostly only horizontal joints are seen, and occasionally one or two steep or vertical joints. However, we know that in the nearby Sigerslev chalk quarry four vertical joint set and one horizontal set is observed (Rosenbom & Jakobsen, 2005). Therefore, more set have been noted in the Jn parameter field than observed in the core.

Two faults are observed at 185 and 269m below surface. At 185m the fault zone was a 5cm wide brecciated zone, delineated by fault planes with slickenside. At 269m the fault zone was a 15cm wide brecciated zone, delineated by fault planes with slickenside. Both breccias where healed and filled with transparent $CaCO_2$, and the breccias where harder than the surrounding chalk, with an induration of H3.

Figure 6. Picture of the fault zone at 185m depth. The fault zone is delineated by fault planes with slickenside. The fault breccia is healed and cemented with calcite. The fault zone has an induration of H3, and the chalk has an induration of H2. The picture also shows the halving of the core and the sampling for paleontological investigations.

Induration

The induration of the limestone is assessed according to Larsen et al. (1988) using a 5 level scale. The assessed induration is shown in appendix 2. The general trend is that the chalk gets more indurated with depth. The chalk has an induration of H2 in the upper part to 265 m below surface. From 265 to 313 m below surface the chalk is a little harder, and the induration is assessed to about H2.5. Below 340 m the induration is assessed to be H3.

Flint

Flint occurs as Layers or horizons of flintnodules, varying in thickness from 1 cm and up to about 15 cm (Fig. 4). Flint occurs in the upper 160m of the core. The flint has an induration of H5.

Marl

Marl occurs as layers and it is grey, clay rich carbonates to carbonate rich clay. The thickness of the marl layers varies from less than 1 cm and up to a little more than 5 cm (Fig. 5). Layers of marl occur mainly in the interval between 310 m and 440 m below surface

During the investigation of the core, which now is dry, the marl seemed to be just as indurated as the chalk. However, according to the geologists who recovered the fresh core, at least some of the marl layers where softer than the chalk. The marl layers are therefore considered weaknes zones, and are consequently given a SRF value of 2.5 and the Jr/Ja values are set to be 1/6 if many ore thick layers occur.

Q-values

Q-values are assessed for each core box, representing approximately 4 m each. The core logging recordings are shown in appendix 1. In figure 2.5 the Q-values are shown for each core box. The Stevns 1 core may be subdivided into 5 intervals with comparable levels of Q-values. The Q mean value, the range of Q-values and the most frequent Q-value is calculated for each interval (see table 1). The average Q-value for each interval is also indicated on figure 2.5, as well as the typical min., typical max. and the most frequent Q values.

The general trend is that the Q-value decreases in interval 2 compared to the upper interval, and than it increases with depth in the intervals 3 and 4. In interval 5 the chalk itself is strong and with high RQD, but the presence of marl layers (Fig. 5), which are assessed to be weaknes zones, reduces the Q values in various parts of the interval and (Fig. 7 and Table 1).

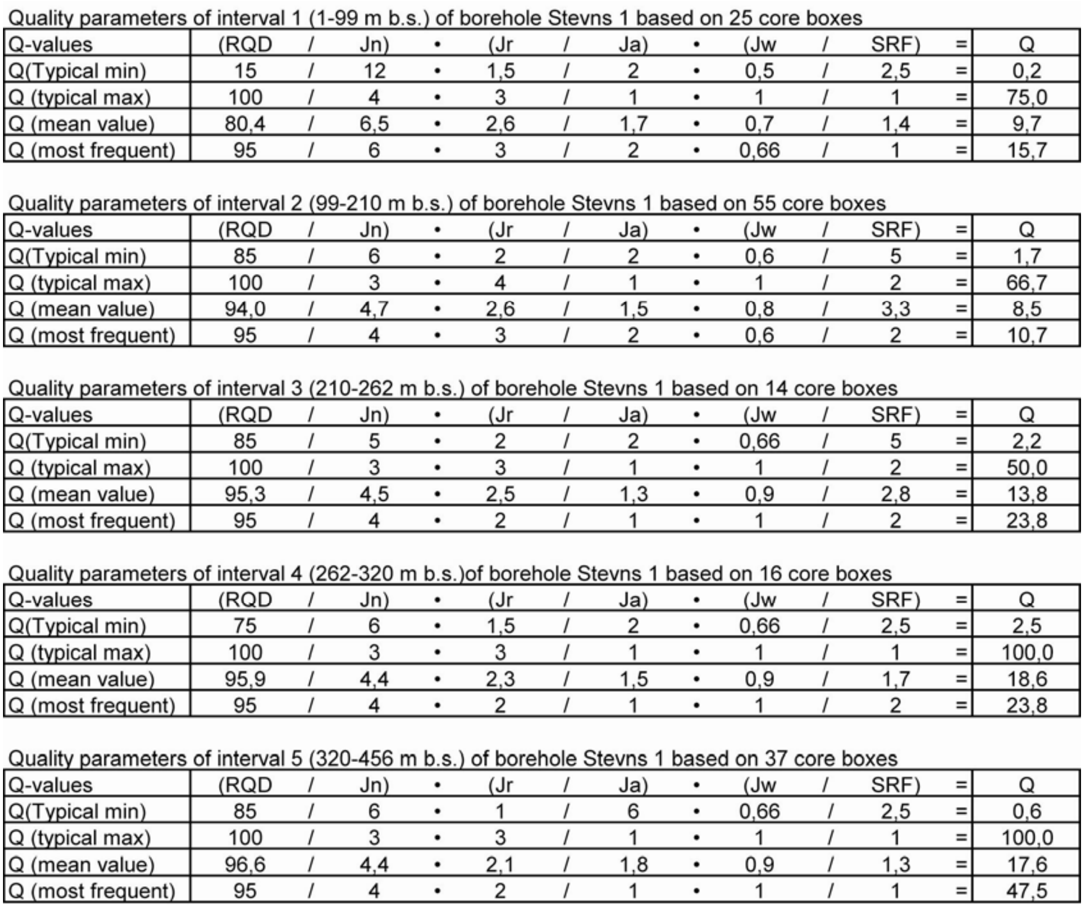
The uppermost interval (1-99m) has varying Q-values mainly caused by different degree of fracturing, and consequently varying RQD values. The mean Q-value is 9.7, which is a fair quality in the Q system design chart (fig. 3).

In the second interval (99-210m) the mean Q-value is decreased to 8.52, mainly because an increase of stress in this depth and no increase in rock strength in this interval. The Q-values are not varying as much as in the interval above (Fig. 7). The slightly less Q value is still in the rock class fair quality according to the Q system design chart (Fig. 3).

In the third interval (210-262m) the mean Q-values are increased to 13.8. This is mainly due to dryer conditions at this depth, and high RQD values. The variation of the Q values is less in this interval (Fig. 7) and the Q mean value corresponds to a good quality according to the Q system design chart (Fig. 3).

In the fourth interval (262-376) the chalk is more indurated leading to smaller SRF values due to assumed lack of stress fracturing and the mean Q-value increases up to 20.

In the interval 5 (376-456m) the chalk is even more indurated, but the presence of marl layers reduces the Q values in various parts of the interval. Some of the marl layers where more soft than the chalk, when the core was fresh and wet. The softness of the marl is depending of the clay content. The marl layers are in this assessment treated conservatively and they are regarded as weaknes zones if many or thich layers occur. Special attention should be given on the marl layers in future exploration holes. The mean Q-value is 17.6, which corresponds to a good quality according to the Q system design chart (Fig. 3). However, the Mean Q-value of boxes with marl layers is about 10 (fair to good quality) and the mean Q-value of the boxes without marl layers (or only few and small layers) is about 30 (Good quality). The large variety is also reflected in the large span between the Q(typical min) and Q(typical max) (Fig. 7). Note also that the Q (most frequent) value is much higher than the Q mean value (Fig. 7) and corresponds to a very good quality according to the Q system design chart (Fig. 3).



Quality parameters of interval 1 (1-99 m b.s.) of borehole Stevns 1 based on 25 core boxes

Q-values	(RQD	/	Jn)	•	(Jr	/	Ja)	•	(Jw	/	SRF)	=	Q
Q(Typical min)	15	/	12	•	1,5	/	2	•	0,5	/	2,5	=	0,2
Q (typical max)	100	/	4	•	3	/	1	•	1	/	1	=	75,0
Q (mean value)	80,4	/	6,5	•	2,6	/	1,7	•	0,7	/	1,4	=	9,7
Q (most frequent)	95	/	6	•	3	/	2	•	0,66	/	1	=	15,7

Quality parameters of interval 2 (99-210 m b.s.) of borehole Stevns 1 based on 55 core boxes

Q-values	(RQD	/	Jn)	•	(Jr	/	Ja)	•	(Jw	/	SRF)	=	Q
Q(Typical min)	85	/	6	•	2	/	2	•	0,6	/	5	=	1,7
Q (typical max)	100	/	3	•	4	/	1	•	1	/	2	=	66,7
Q (mean value)	94,0	/	4,7	•	2,6	/	1,5	•	0,8	/	3,3	=	8,5
Q (most frequent)	95	/	4	•	3	/	2	•	0,6	/	2	=	10,7

Quality parameters of interval 3 (210-262 m b.s.) of borehole Stevns 1 based on 14 core boxes

Q-values	(RQD	/	Jn)	•	(Jr	/	Ja)	•	(Jw	/	SRF)	=	Q
Q(Typical min)	85	/	5	•	2	/	2	•	0,66	/	5	=	2,2
Q (typical max)	100	/	3	•	3	/	1	•	1	/	2	=	50,0
Q (mean value)	95,3	/	4,5	•	2,5	/	1,3	•	0,9	/	2,8	=	13,8
Q (most frequent)	95	/	4	•	2	/	1	•	1	/	2	=	23,8

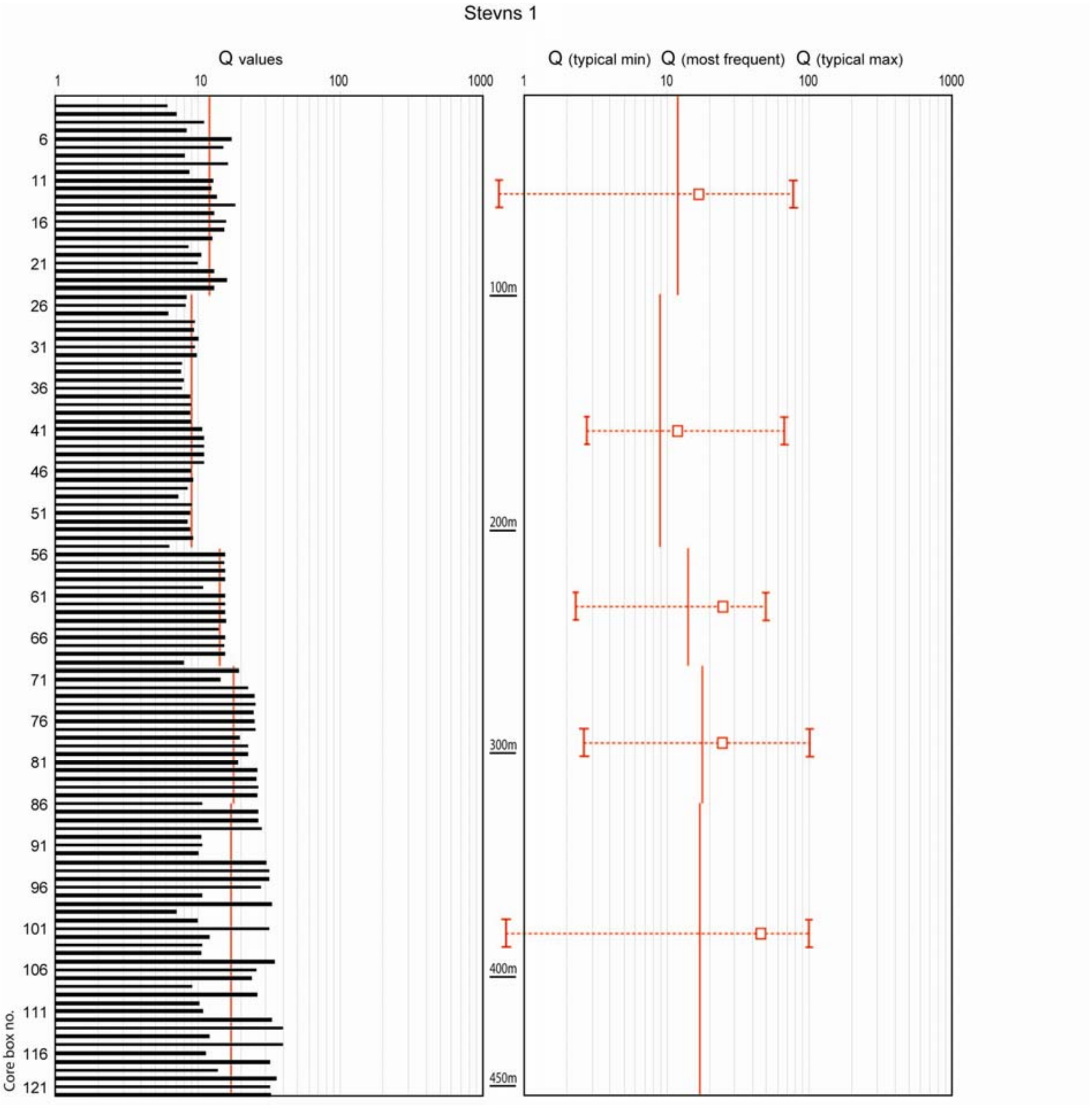
Quality parameters of interval 4 (262-320 m b.s.)of borehole Stevns 1 based on 16 core boxes

Q-values	(RQD	/	Jn)	•	(Jr	/	Ja)	•	(Jw	/	SRF)	=	Q
Q(Typical min)	75	/	6	•	1,5	/	2	•	0,66	/	2,5	=	2,5
Q (typical max)	100	/	3	•	3	/	1	•	1	/	1	=	100,0
Q (mean value)	95,9	/	4,4	•	2,3	/	1,5	•	0,9	/	1,7	=	18,6
Q (most frequent)	95	/	4	•	2	/	1	•	1	/	2	=	23,8

Quality parameters of interval 5 (320-456 m b.s.) of borehole Stevns 1 based on 37 core boxes

Q-values	(RQD	/	Jn)	•	(Jr	/	Ja)	•	(Jw	/	SRF)	=	Q
Q(Typical min)	85	/	6	•	1	/	6	•	0,66	/	2,5	=	0,6
Q (typical max)	100	/	3	•	3	/	1	•	1	/	1	=	100,0
Q (mean value)	96,6	/	4,4	•	2,1	/	1,8	•	0,9	/	1,3	=	17,6
Q (most frequent)	95	/	4	•	2	/	1	•	1	/	1	=	47,5

Table1. Quality parameters of 5 intervals in the Stevns 1 borehole.



Interval	Box- interval	Depth (m)	Q mean value	Q (typical min)	Q (most frequent)	Q (typical max)
1	1-25	1-99	9.7	0.2	15.7	75
2	25-55	99-210	8.5	1.7	10.7	67
3	56-69	210-262	13.8	2.2	23.8	50
4	70-85	262-320	18.8	2.5	23.8	100
5	86-122	320-456	17.6	0.6	47.5	100

Figure 7. Q-values assessed for each Box in the Stevns 1 boring. Q mean values for 5 intervals with comparable levels of Q-values are marked with the red lines. On the right the values of Q(typical min), Q(most frequent) and Q(typical max) are indicated.

Rørdal 2

Quality of the core

The uppermost 33.8m where crushed during the drilling (Fig. 3.1 A). The rest of the core was subjected to slabbing/halving (Fig. 3.1 B). Quality assessment of the core has subsequently been performed from 33.8m to 101.8m.

Figure 8A. An example of the crushed core from the depth interval 8.55m to 9.65m. Figure 8B. An example of the core from the depth interval 45.10-46.60m. Note the halving of the core. Not all the breaks are natural joints.

Geology of the core

The core consists of chalk of Cretaceous age. Only few layers of flint are observed and no marl layers are seen in this core.

Joints

It was not possible to assess the fracturing in the upper 34m due to the state of the core.

Mostly, only horizontal joints set are seen, and occasionally one or two additional steep or vertical joint set. However, we know from investigations in the Rørdal quarry that faults and joints of two or more vertical sets are observed, along with horizontal fracturing (Thrane & Zinck-Jørgensen, 1997). Therefore, more joint set have been noted in the Jn parameter field than observed in the core.

Induration

The induration of the limestone is assessed using a 5 level scale (Larsen et al., 1988). The chalk has an induration of H2 in the whole core length (H2= weakly hardened).

Flint

Only three minor flint layers occur in this core and they are situated at 31.3 m, 37.2m and 38.7 m below surface.

Q-values

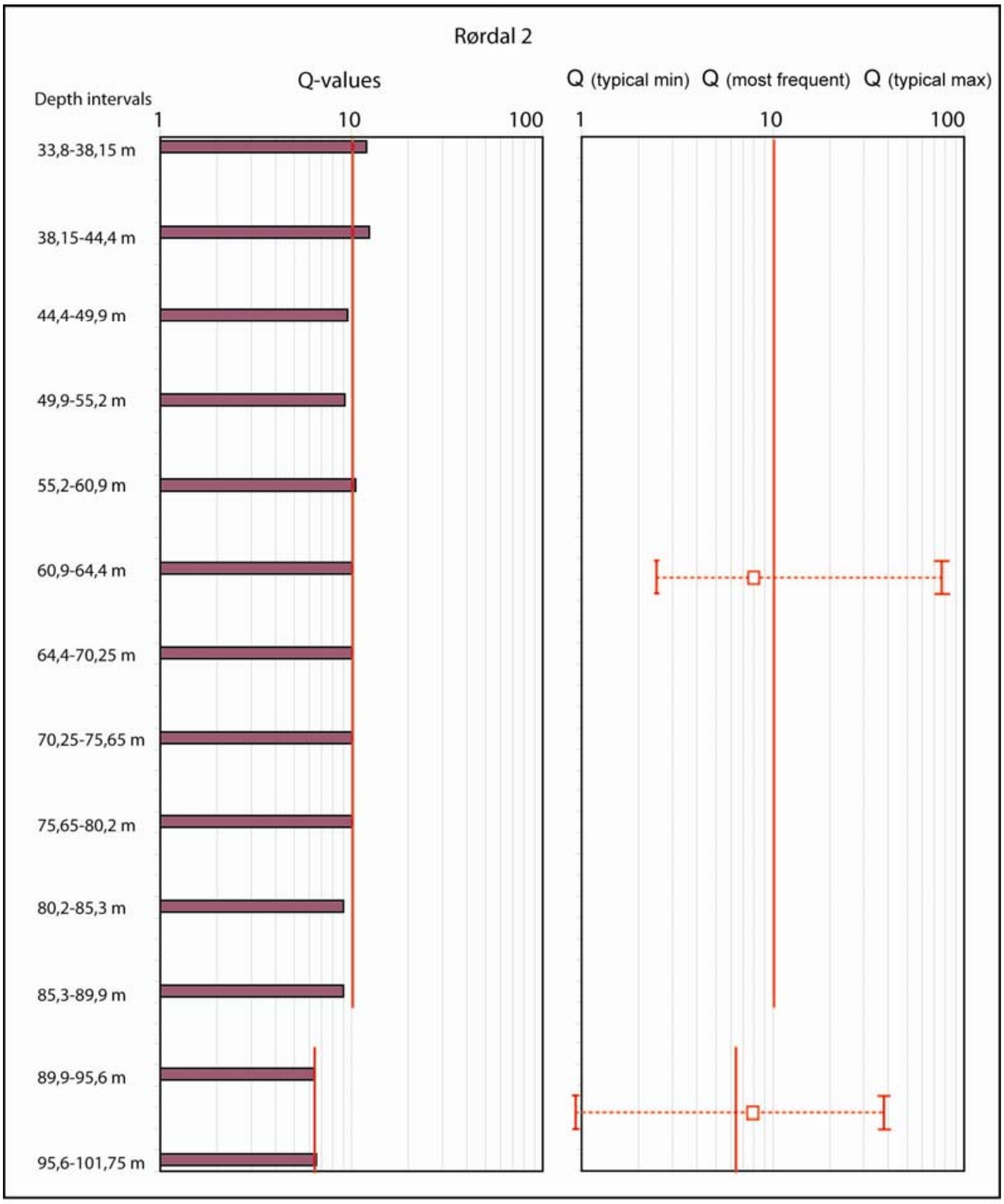
Q-values are assessed for about 5m intervals in the Rørdal 2 boring. The core logging recordings are shown in appendix 1. In the lower most part of the Rørdal boring it is assessed that there is an increase in stress, but no increase of strength is seen (the same induration). Consequently the Q-value decreases in the lowermost 10 m of the boring as the SRF values are assumed to be higher. Consequently two intervals with comparable levels of Q-values are chosen (Fig. 3.2).

The Q mean value, the range of Q-values and the most frequent Q-value is calculated for each interval and shown on figure 9.

The mean Q-value from 33m to 89.9m below surface is 10.03, which corresponds to a good quality according to the Q system design chart (Fig. 3).

The mean Q-value from 89.9m to 101m below surface is 6.49, which corresponds to a fair quality according to the Q system design chart (fig. 1.2). The assessed decrease in Q value is due to an assessed increase of the SRF values, as the stress is increasing with depth and no increase in rock strength (induration) is observed in this interval.

The most frequent Q value is, however, the same for the whole interval from 33m to 101m b.s. (Fig. 9)



Quality parameters of interval 1 (1-89,9 m b.s.) of borehole based on 11 core intervals

Q-values	(RQD	/	Jn)	•	(Jr	/	Ja)	•	(Jw	/	SRF)	=	Q
Q(Typical min)	85	/	9	•	2	/	2	•	0,5	/	2	=	2,4
Q (typical max)	100	/	4	•	3	/	1	•	1	/	1	=	75,0
Q (mean value)	94,1	/	6,3	•	2,5	/	1,6	•	0,7	/	1,6	=	10,0
Q (most frequent)	95	/	6	•	3	/	2	•	0,66	/	2	=	7,8

Quality parameters of interval 2 (89,9-101,75 m b.s.) of borehole based on 2 core intervals

Q-values	(RQD	/	Jn)	•	(Jr	/	Ja)	•	(Jw	/	SRF)	=	Q
Q(Typical min)	85	/	9	•	2	/	2	•	0,5	/	5	=	0,9
Q (typical max)	100	/	4	•	3	/	1	•	1	/	2	=	37,5
Q (mean value)	95,0	/	6,3	•	2,5	/	1,5	•	0,7	/	2,8	=	6,5
Q (most frequent)	95	/	6	•	3	/	2	•	0,66	/	2	=	7,8

Figure 9. Left: Q-values assessed for about 5 m intervals in the Rørdal 2 boring. Q mean values for 2 intervals with comparable levels of Q-values are marked with the red vertical lines. Right: the values of Q(typical min), Q(most frequent) and Q(typical max) are indicated. Bottom: Quality parameters are given in the table of two intervals in the Rørdal 2 borehole.

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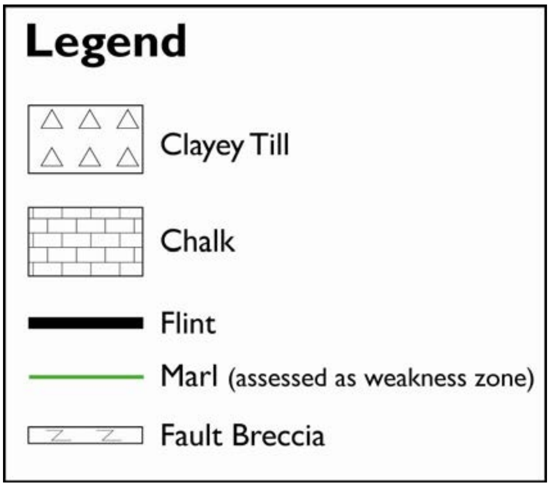
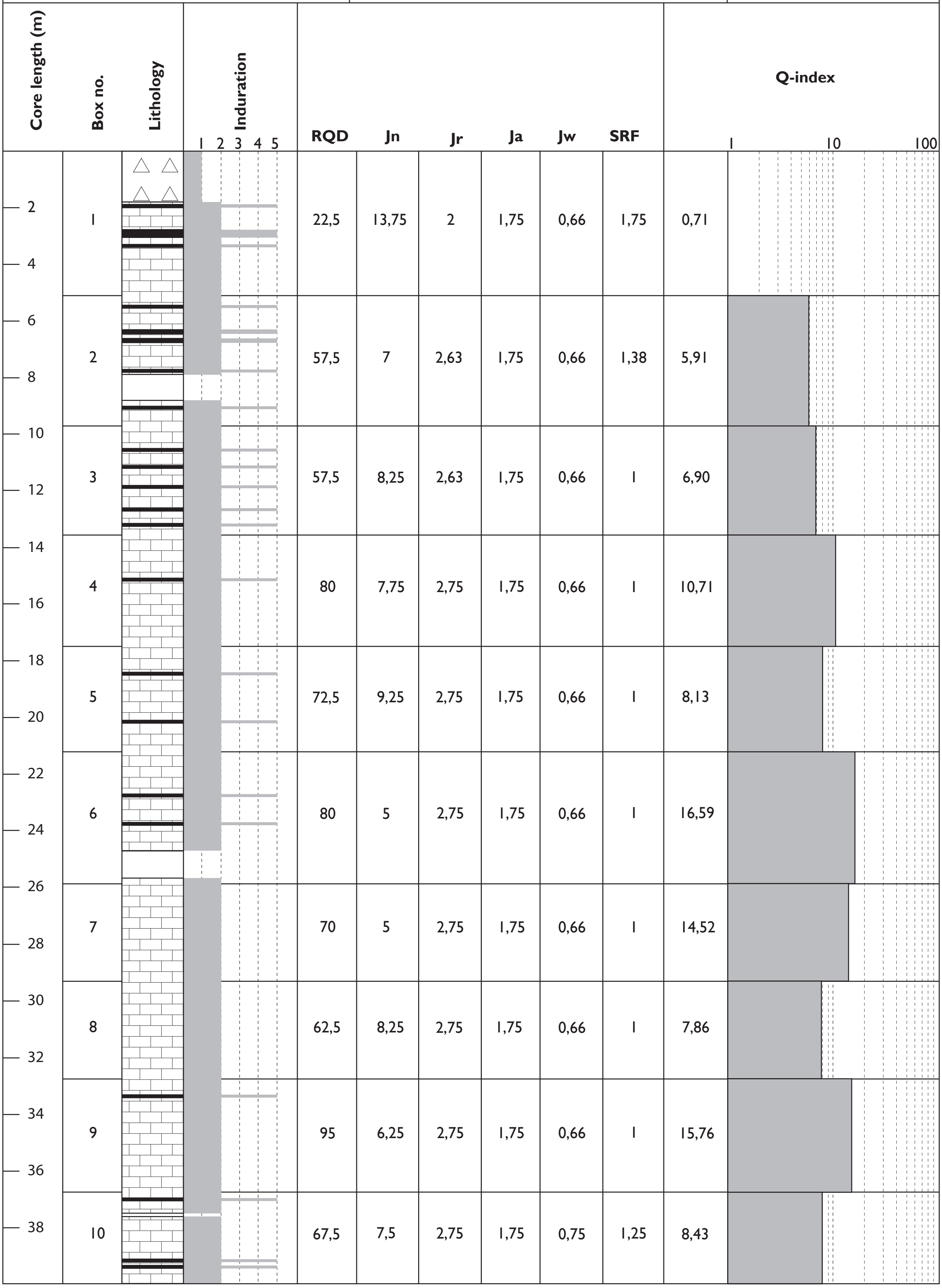
Q rating data from Stevns 1 and Rørdal 2

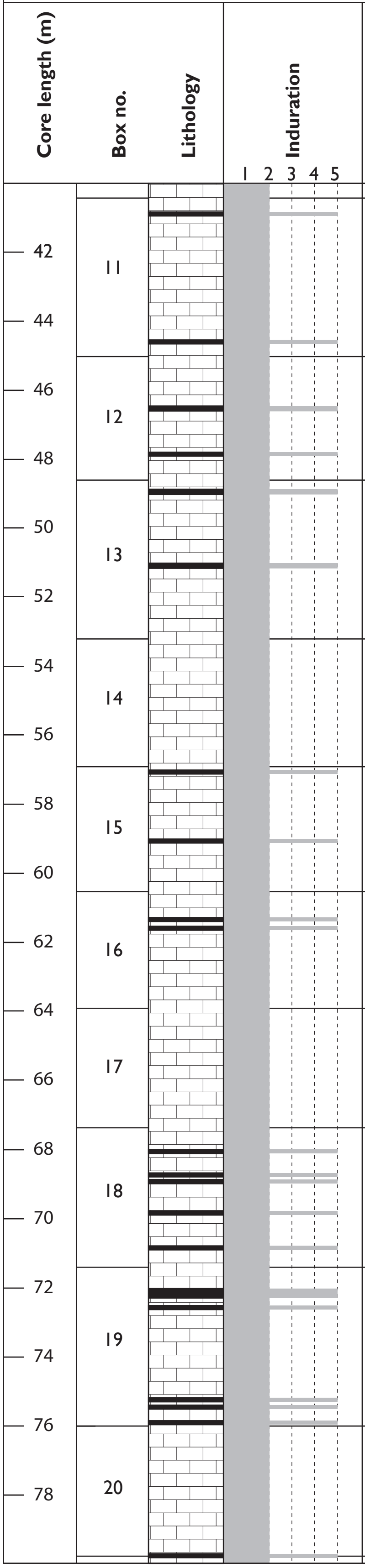


Q - rating	**Page:** 1 **of:** 12	GEUS
STEVNS 1	**Rep no:** **Init:** PRJ/SROE	



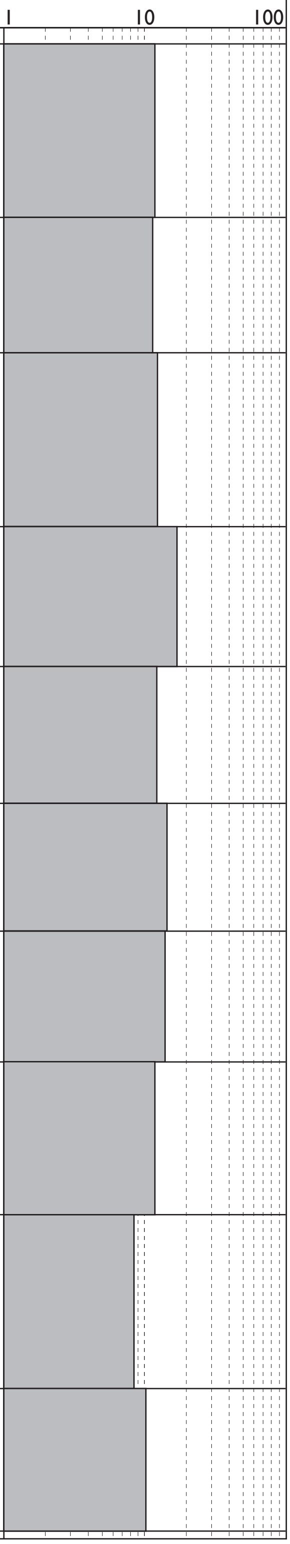
Box no.	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
1	22,5	13,75	2	1,75	0,66	1,75	0,71
2	57,5	7	2,63	1,75	0,66	1,38	5,91
3	57,5	8,25	2,63	1,75	0,66	1	6,90
4	80	7,75	2,75	1,75	0,66	1	10,71
5	72,5	9,25	2,75	1,75	0,66	1	8,13
6	80	5	2,75	1,75	0,66	1	16,59
7	70	5	2,75	1,75	0,66	1	14,52
8	62,5	8,25	2,75	1,75	0,66	1	7,86
9	95	6,25	2,75	1,75	0,66	1	15,76
10	67,5	7,5	2,75	1,75	0,75	1,25	8,43

Q - rating	**Page:** 2 **of:** 12	GEUS
STEVNS 1	**Rep no:**	
	Init: PRJ/SROE	



Box no.	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
11	82,5	6,25	2,75	1,75	0,75	1,25	12,36
12	80	6,25	2,75	1,75	0,75	1,25	11,99
13	87,5	6,25	2,75	1,75	0,75	1,25	13,11
14	90	4,75	2,75	1,75	0,75	1,25	17,75
15	92,5	5,75	2,75	1,75	0,75	1,50	12,56
16	92,5	5	2,50	1,50	0,75	1,50	15,31
17	90	5	2,50	1,50	0,75	1,50	14,90
18	92,5	6,25	2,50	1,50	0,75	1,50	12,25
19	77,5	7,5	3,00	1,50	0,71	1,75	8,33
20	95	6,25	2,50	1,50	0,71	1,75	10,21

Q-index



Q - rating	**Page:** 3 **of:** 12
STEVNS 1	**Rep no:**
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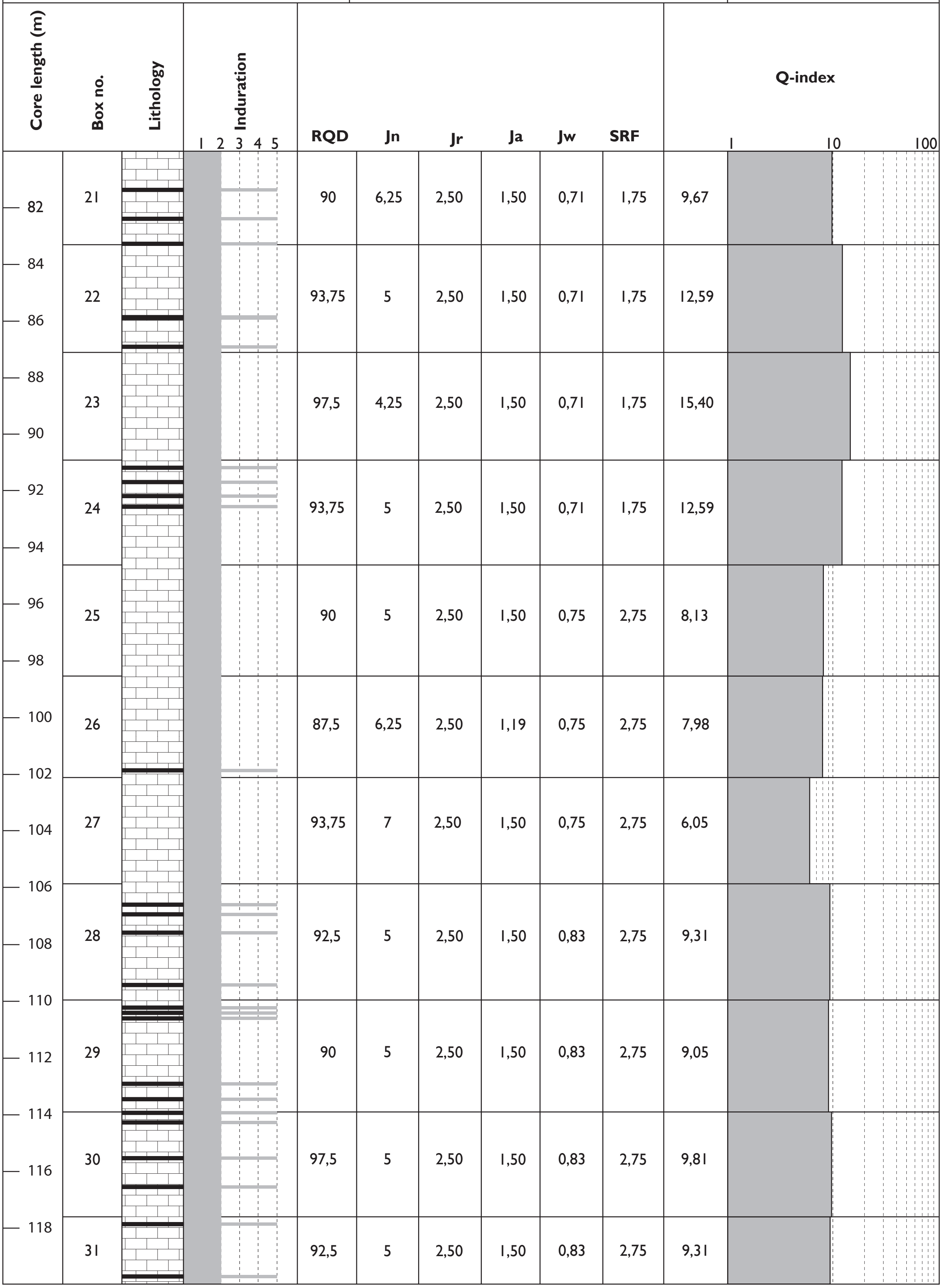

Box no.	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
21	90	6,25	2,50	1,50	0,71	1,75	9,67
22	93,75	5	2,50	1,50	0,71	1,75	12,59
23	97,5	4,25	2,50	1,50	0,71	1,75	15,40
24	93,75	5	2,50	1,50	0,71	1,75	12,59
25	90	5	2,50	1,50	0,75	2,75	8,13
26	87,5	6,25	2,50	1,19	0,75	2,75	7,98
27	93,75	7	2,50	1,50	0,75	2,75	6,05
28	92,5	5	2,50	1,50	0,83	2,75	9,31
29	90	5	2,50	1,50	0,83	2,75	9,05
30	97,5	5	2,50	1,50	0,83	2,75	9,81
31	92,5	5	2,50	1,50	0,83	2,75	9,31

Q - rating | **Page:** 4 **of:** 12

STEVNS 1

Rep no:

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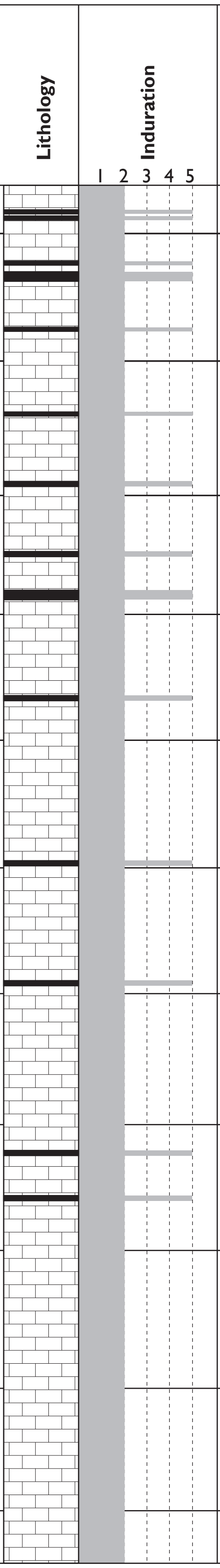
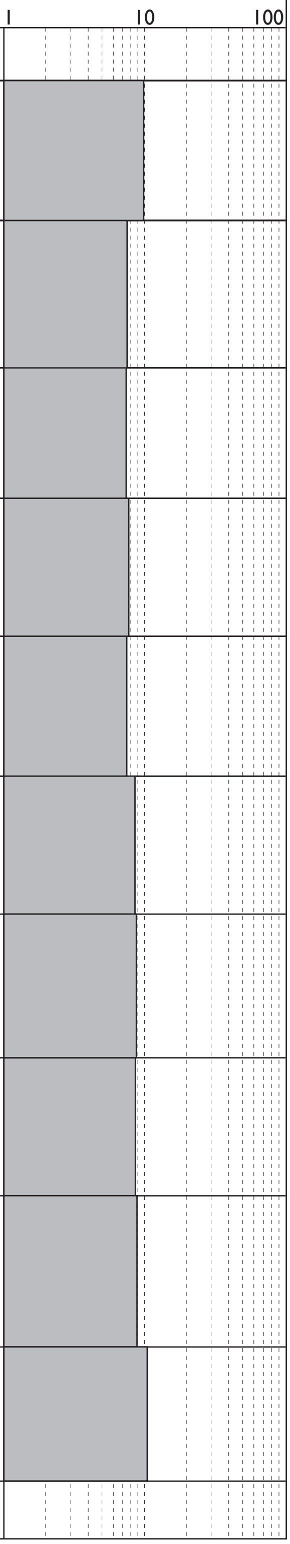


Core length (m)	Box no.	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
122 124	32	95	5	2,50	1,50	0,83	2,75	9,56
126 128	33	95	5	2,50	1,50	0,83	3,50	7,51
130 132	34	93,75	5	2,50	1,50	0,83	3,50	7,41
134 136	35	97,5	5	2,50	1,50	0,83	3,50	7,71
138	36	95	5	2,50	1,50	0,83	3,50	7,51
140 142	37	92,5	4,25	2,50	1,50	0,83	3,50	8,60
144 146	38	93,75	4,25	2,50	1,50	0,83	3,50	8,72
148 150	39	92,5	4,25	2,50	1,50	0,83	3,50	8,60
152 154	40	93,75	4,25	2,50	1,50	0,83	3,50	8,72
156 158	41	93,75	4,25	3,00	1,50	0,83	3,50	10,46



Q - rating

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STEVNS 1

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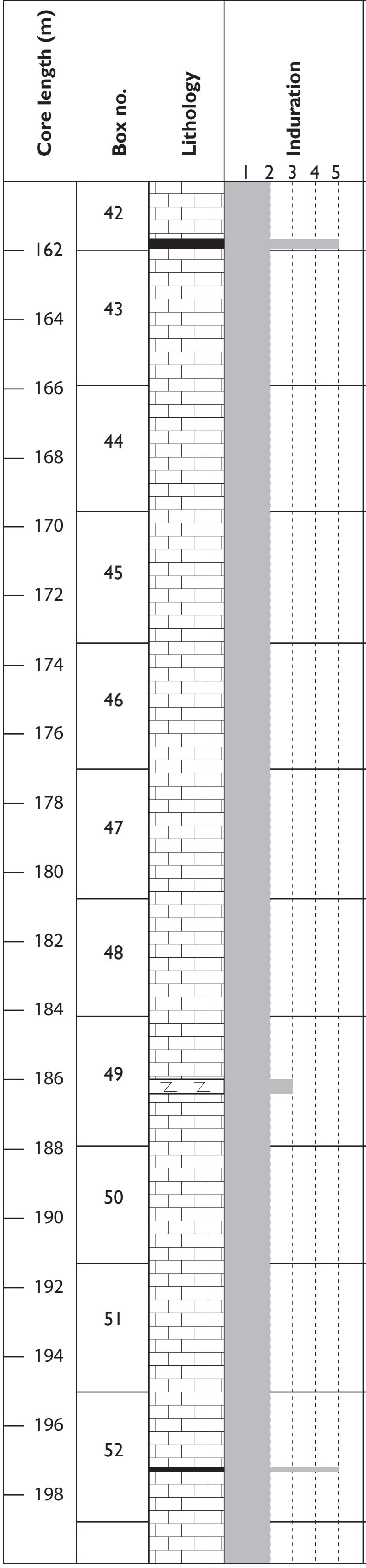
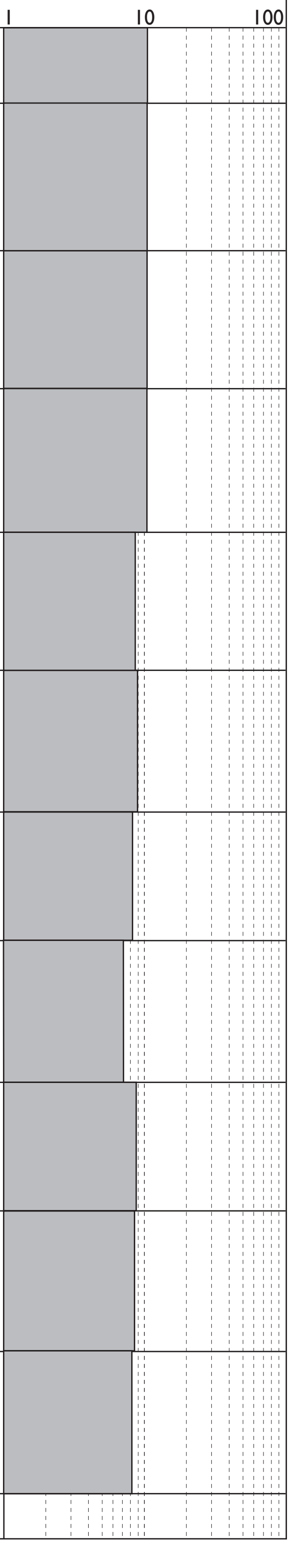


Box no.	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
42	96,25	4,25	3,00	1,50	0,83	3,50	10,74
43	96,25	4,25	3,00	1,50	0,83	3,50	10,74
44	96,25	4,25	3,00	1,50	0,83	3,50	10,74
45	96,25	4,25	3,00	1,50	0,83	3,50	10,74
46	93,75	4,25	2,50	1,50	0,83	3,50	8,72
47	96,25	4,25	2,50	1,50	0,83	3,50	8,95
48	92,5	4,25	2,38	1,50	0,83	3,50	8,17
49	90	4,25	2,13	1,50	0,83	3,50	7,11
50	95	4,25	2,50	1,50	0,83	3,50	8,83
51	92,5	4,25	2,50	1,50	0,83	3,50	8,60
52	97,5	4,25	2,25	1,50	0,83	3,50	8,16



Q - rating	**Page:** 6 **of:** 12
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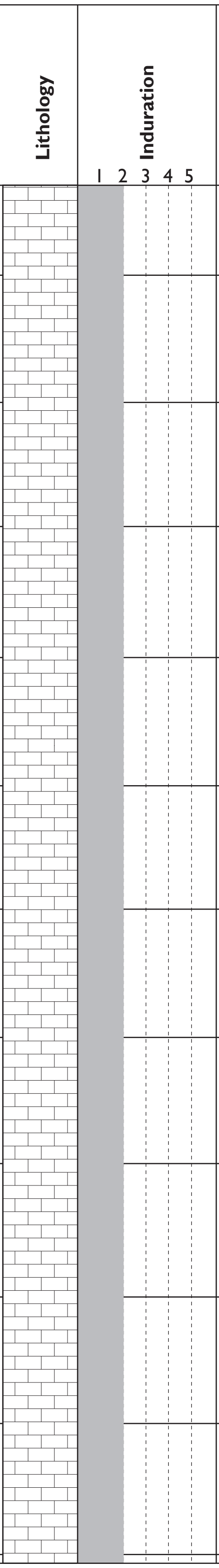
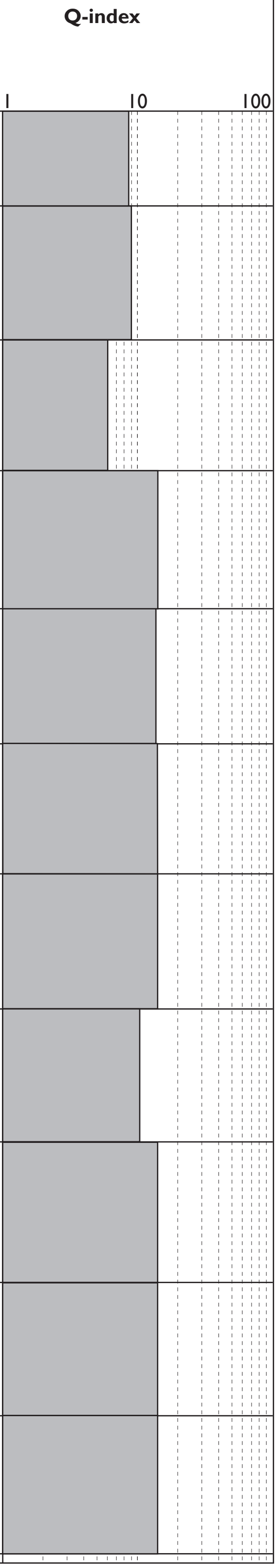
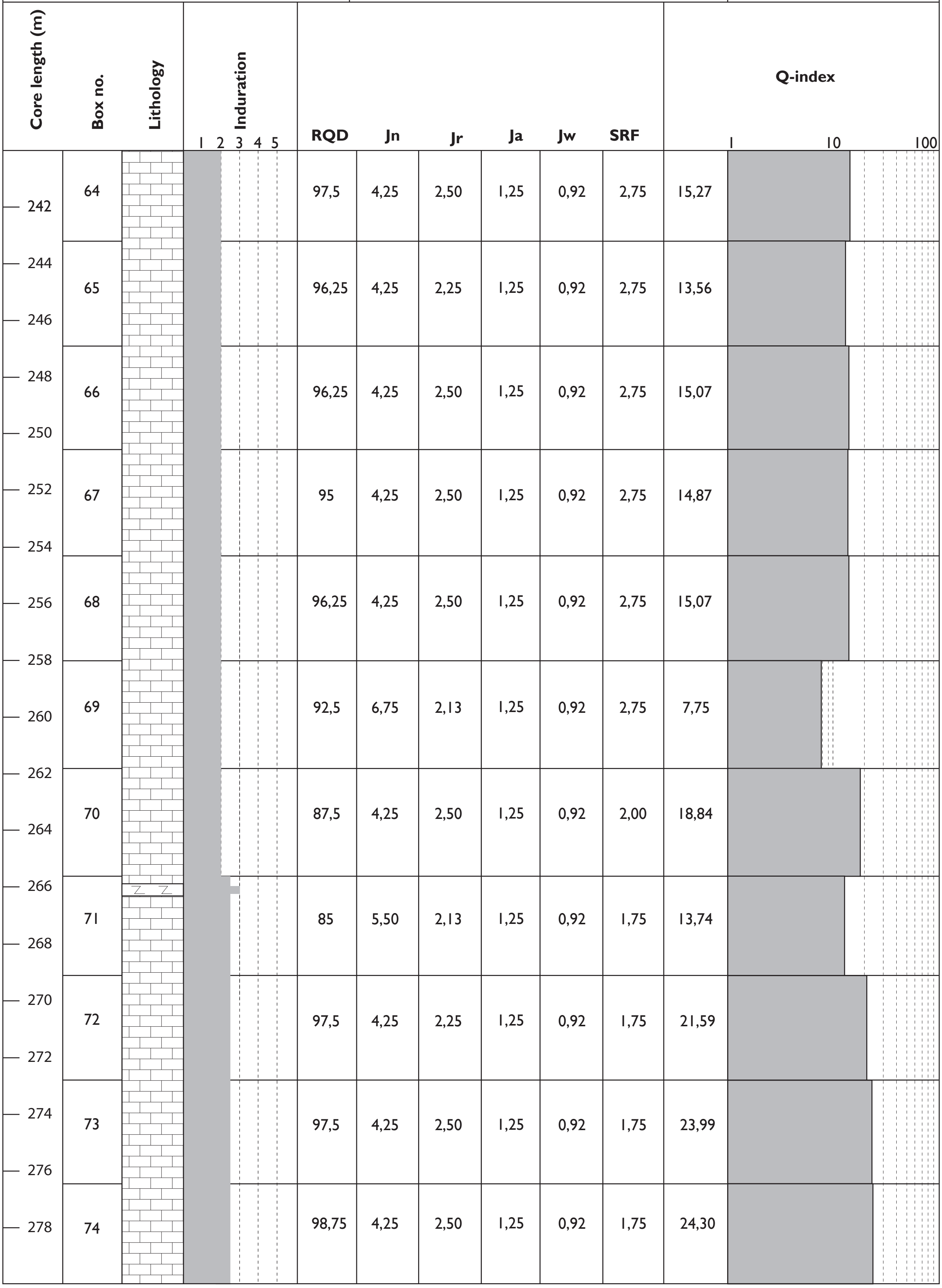


Core length (m)	Box no.	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
202	53	92,5	4,25	2,50	1,50	0,83	3,50	8,60
204 206	54	96,25	4,25	2,50	1,50	0,83	3,50	8,95
208	55	93,75	5,5	2,38	2,00	0,83	2,75	6,11
210 212	56	96,25	4,25	2,50	1,25	0,92	2,75	15,07
214 216	57	95	4,25	2,50	1,25	0,92	2,75	14,87
218 220	58	96,25	4,25	2,50	1,25	0,92	2,75	15,07
222 224	59	96,25	4,25	2,50	1,25	0,92	2,75	15,07
226 228	60	87,5	5	2,50	1,25	0,83	2,75	10,56
230 232	61	96,25	4,25	2,50	1,25	0,92	2,75	15,07
234	62	96,25	4,25	2,50	1,25	0,92	2,75	15,07
236 238	63	96,25	4,25	2,50	1,25	0,92	2,75	15,07



Q - rating	Page: 7 of: 12
STEVNS 1	Rep no:
	Init: PRJ/SROE



Box no.	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
64	97,5	4,25	2,50	1,25	0,92	2,75	15,27
65	96,25	4,25	2,25	1,25	0,92	2,75	13,56
66	96,25	4,25	2,50	1,25	0,92	2,75	15,07
67	95	4,25	2,50	1,25	0,92	2,75	14,87
68	96,25	4,25	2,50	1,25	0,92	2,75	15,07
69	92,5	6,75	2,13	1,25	0,92	2,75	7,75
70	87,5	4,25	2,50	1,25	0,92	2,00	18,84
71	85	5,50	2,13	1,25	0,92	1,75	13,74
72	97,5	4,25	2,25	1,25	0,92	1,75	21,59
73	97,5	4,25	2,50	1,25	0,92	1,75	23,99
74	98,75	4,25	2,50	1,25	0,92	1,75	24,30

Q - rating

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STEVNS 1

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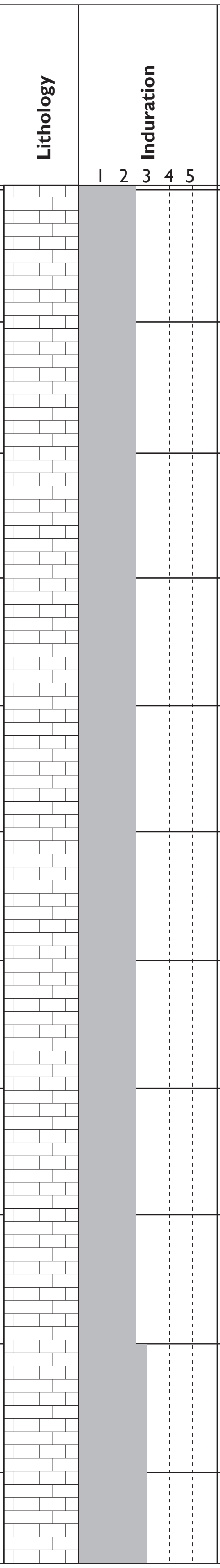
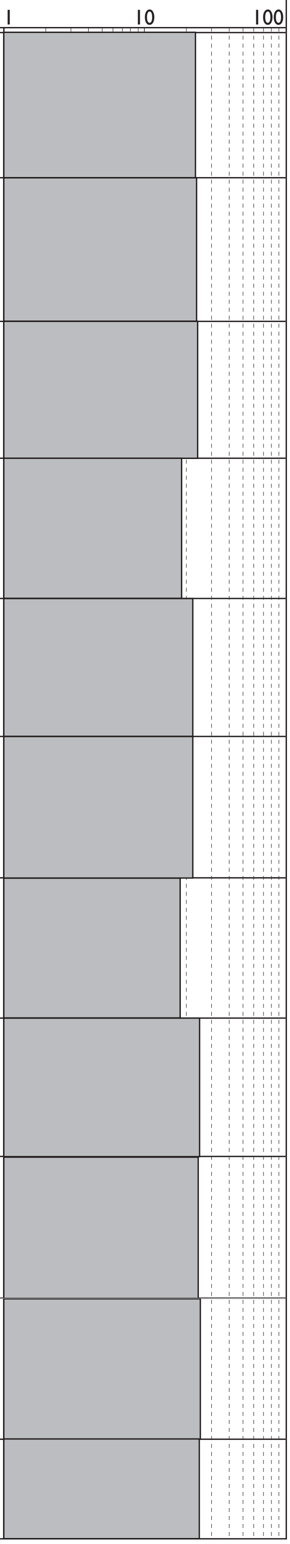


Core length (m)	Box no.	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
282	75	96,25	4,25	2,50	1,25	0,92	1,75	23,68
284 286	76	97,5	4,25	2,50	1,25	0,92	1,75	23,99
288 290	77	98,75	4,25	2,50	1,25	0,92	1,75	24,30
292 294	78	96,25	4,25	2,50	1,25	0,92	1,75	18,95
296 298	79	97,5	4,25	2,25	1,25	0,92	1,75	21,59
300 302	80	97,5	4,25	2,25	1,25	0,92	1,75	21,59
304 306	81	93,75	4,75	2,25	1,25	0,92	1,75	18,58
308	82	97,5	4,25	2,25	1,25	0,92	1,50	25,19
310 312	83	96,25	4,25	2,25	1,25	0,92	1,50	24,87
314 316	84	98,75	4,25	2,25	1,25	0,92	1,50	25,51
318	85	97,5	4,25	2,25	1,25	0,92	1,50	25,19



Q - rating

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STEVNS 1

Rep no:

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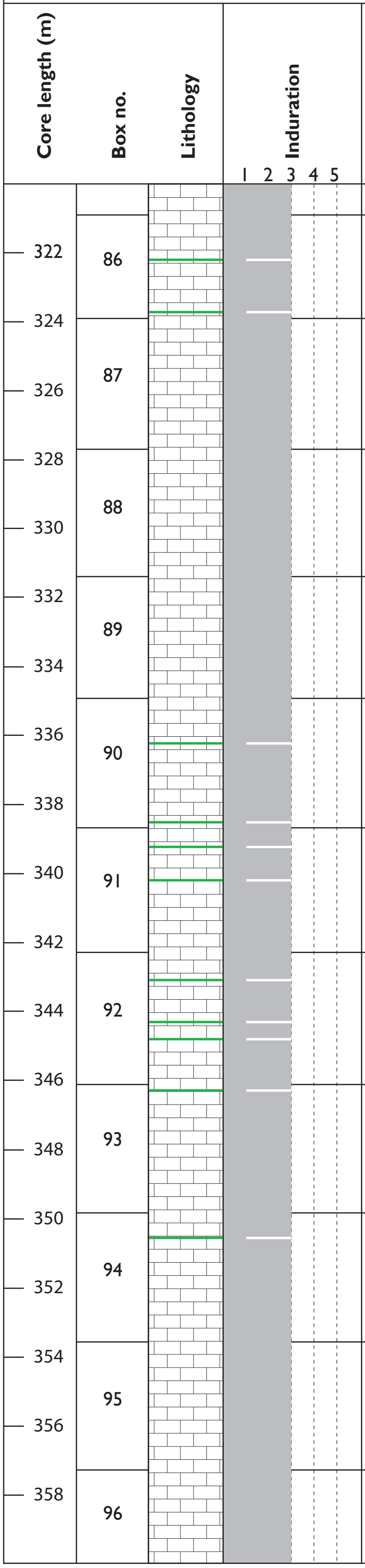
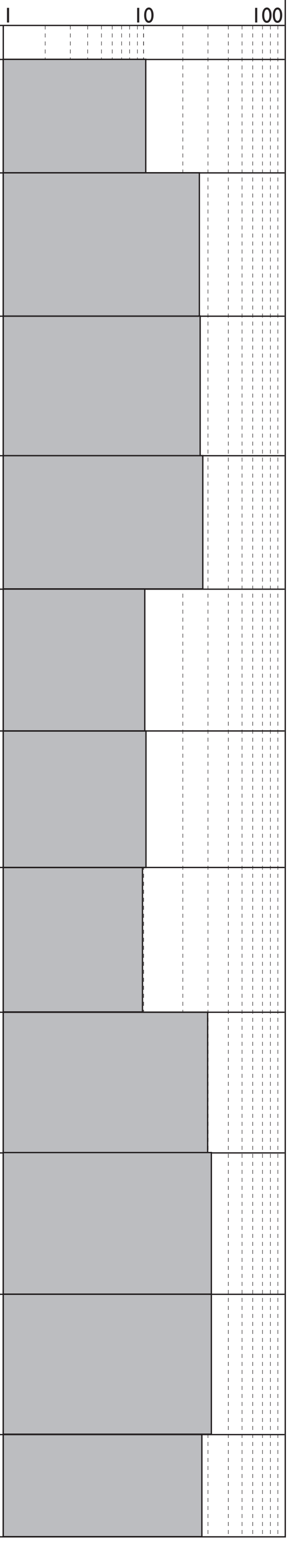


Box no.	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
86	98,75	4,25	2,00	2,50	0,92	1,63	10,47
87	98,75	4,25	2,25	1,25	0,92	1,50	25,51
88	98,75	4,25	2,25	1,25	0,92	1,50	25,57
89	93,75	4,25	2,50	1,25	0,92	1,50	26,91
90	96,25	4,25	2,00	2,50	0,92	1,63	10,20
91	98,75	4,25	2,00	2,50	0,92	1,63	10,47
92	92,5	4,25	2,00	2,50	0,92	1,63	9,80
93	98,75	4,25	2,13	1,25	0,92	1,25	28,91
94	97,5	4,25	2,25	1,25	0,92	1,25	30,23
95	97,5	4,25	2,25	1,25	0,92	1,25	30,23
96	96,25	4,25	2,00	1,25	0,92	1,25	26,52



Q - rating	**Page:** 10 **of:** 12
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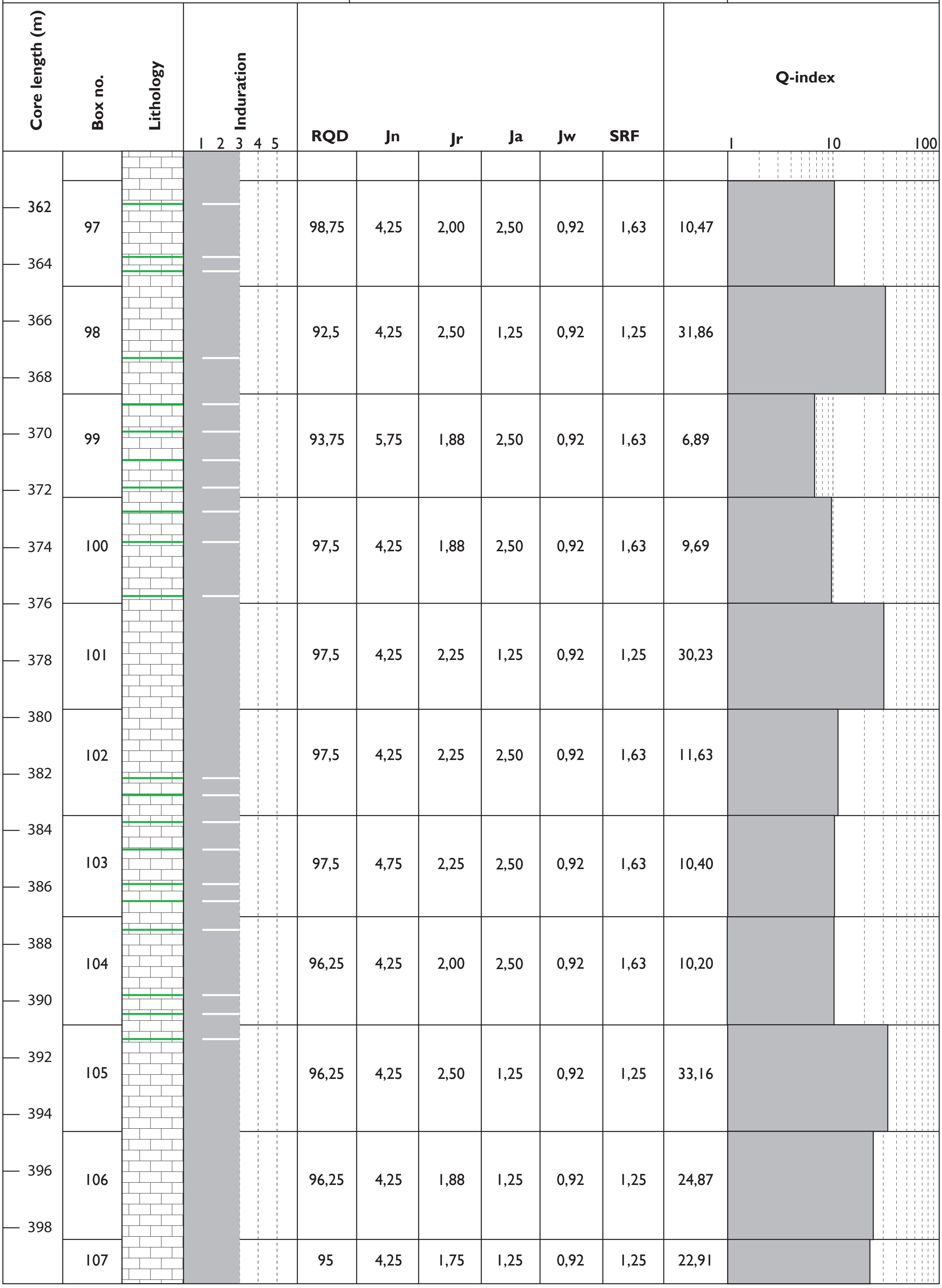

Box no.	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
97	98,75	4,25	2,00	2,50	0,92	1,63	10,47
98	92,5	4,25	2,50	1,25	0,92	1,25	31,86
99	93,75	5,75	1,88	2,50	0,92	1,63	6,89
100	97,5	4,25	1,88	2,50	0,92	1,63	9,69
101	97,5	4,25	2,25	1,25	0,92	1,25	30,23
102	97,5	4,25	2,25	2,50	0,92	1,63	11,63
103	97,5	4,75	2,25	2,50	0,92	1,63	10,40
104	96,25	4,25	2,00	2,50	0,92	1,63	10,20
105	96,25	4,25	2,50	1,25	0,92	1,25	33,16
106	96,25	4,25	1,88	1,25	0,92	1,25	24,87
107	95	4,25	1,75	1,25	0,92	1,25	22,91

Q - rating

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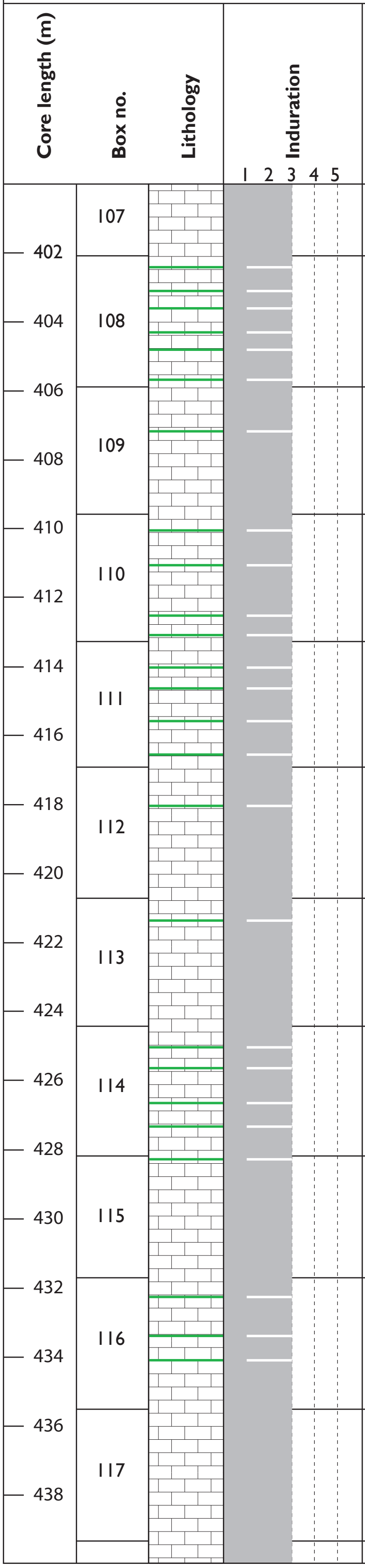
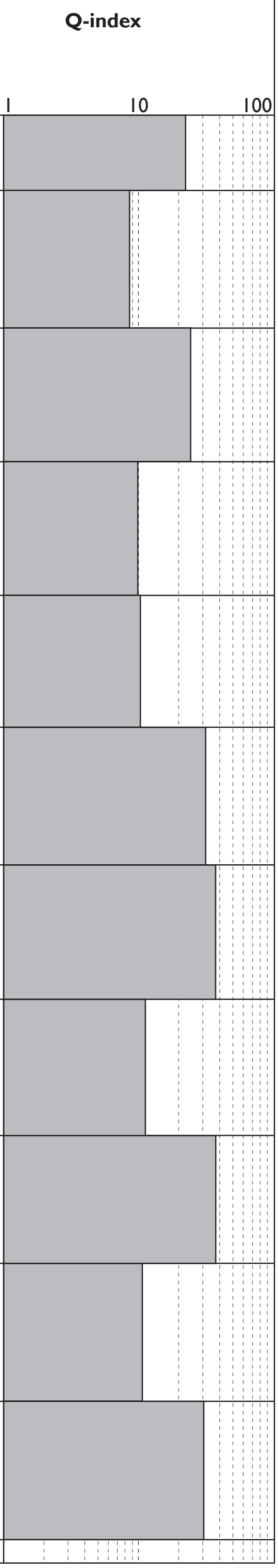
STEVNS 1

Rep no:

Init: PRJ/SROE



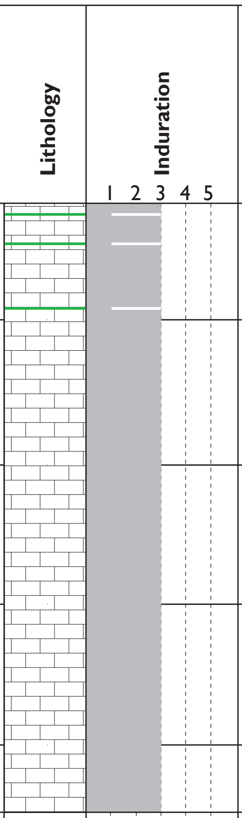
Box no.	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
107	95	4,25	1,75	1,25	0,92	1,25	22,91
108	95	4,25	1,75	2,50	0,92	1,63	8,81
109	93,75	5,5	2,50	1,25	0,92	1,25	24,95
110	97,5	4,25	1,63	2,50	0,92	1,38	9,92
111	96,25	4,25	1,75	2,50	0,92	1,38	10,55
112	98,75	4,25	1,88	1,25	0,92	1,00	31,89
113	97,5	4,25	2,25	1,25	0,92	1,00	37,78
114	96,25	4,75	2,13	2,44	0,92	1,38	11,76
115	97,5	4,25	2,25	1,25	0,92	1,00	37,78
116	93,75	4,75	1,88	2,50	0,92	1,38	11,01
117	95	4,25	1,88	1,25	0,92	1,00	30,68

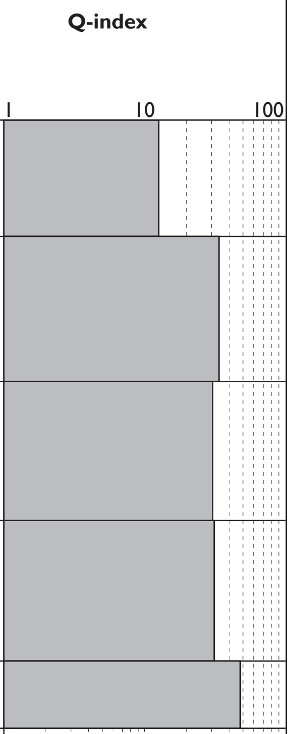


Q - rating	Page: 12 of: 12	GEUS
STEVNS 1	**Rep no:**	
	Init: PRJ/SROE	

Core length (m): 442, 444, 446, 448, 450, 452, 454, 456, 458, 460, 462, 464, 466, 468, 470, 472, 474, 476, 478

Box no.	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
118	96,25	4,25	2,00	2,25	0,92	1,38	13,40
119	95	5,75	2,13	0,94	0,92	1,00	34,27
120	96,25	5	1,75	1,00	0,92	1,00	30,82
121	97,5	4,25	1,88	1,25	0,92	1,00	31,49
122	100	3,75	2,25	1,25	1	1,00	48,00





Q - rating

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RØRDAL 2

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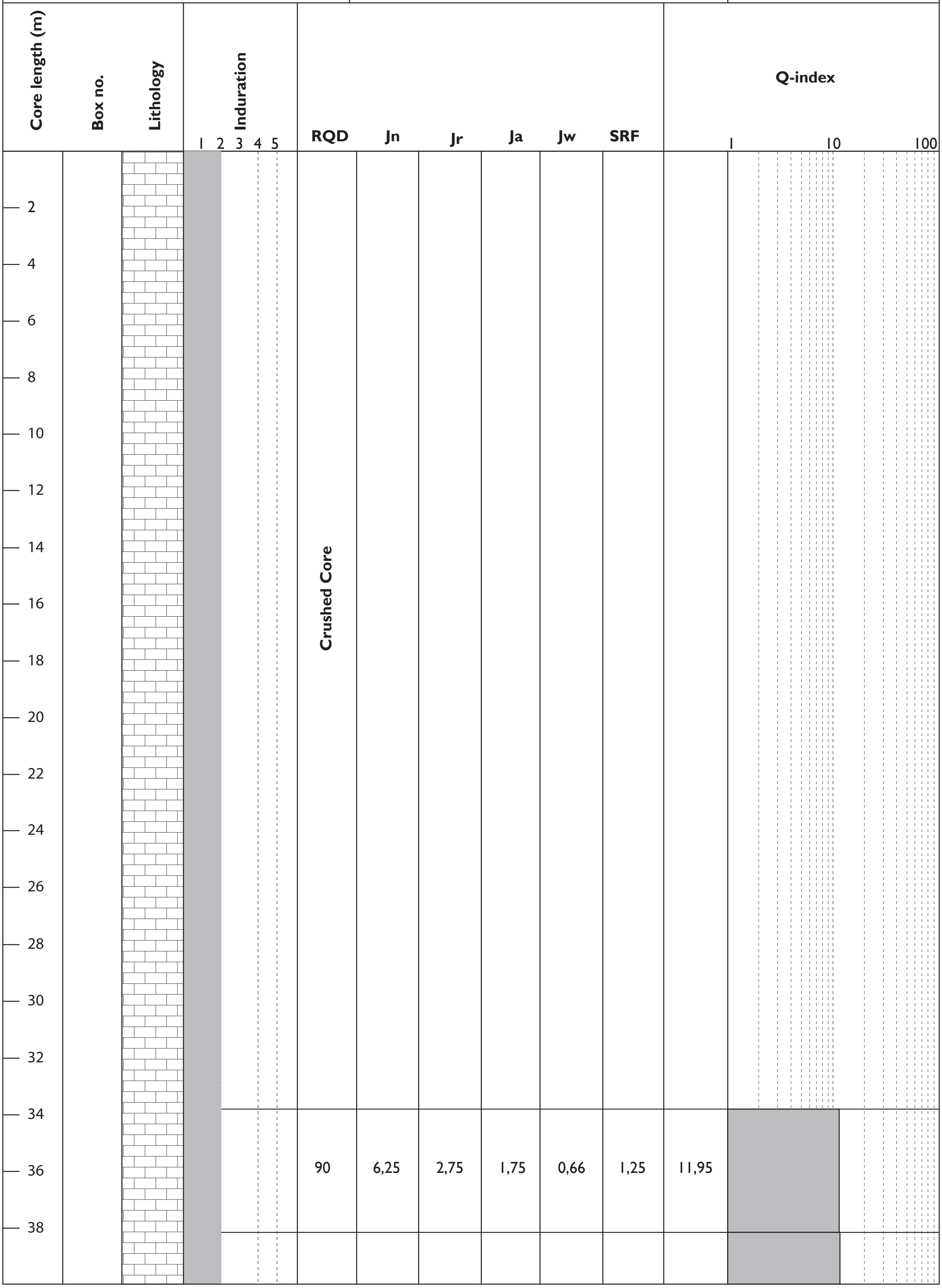


Core length (m)	Box no.	Lithology	Induration	RQD	Jn	Jr	Ja	Jw	SRF	Q-index
				Crushed Core						
				90	6,25	2,75	1,75	0,66	1,25	11,95

Q - rating

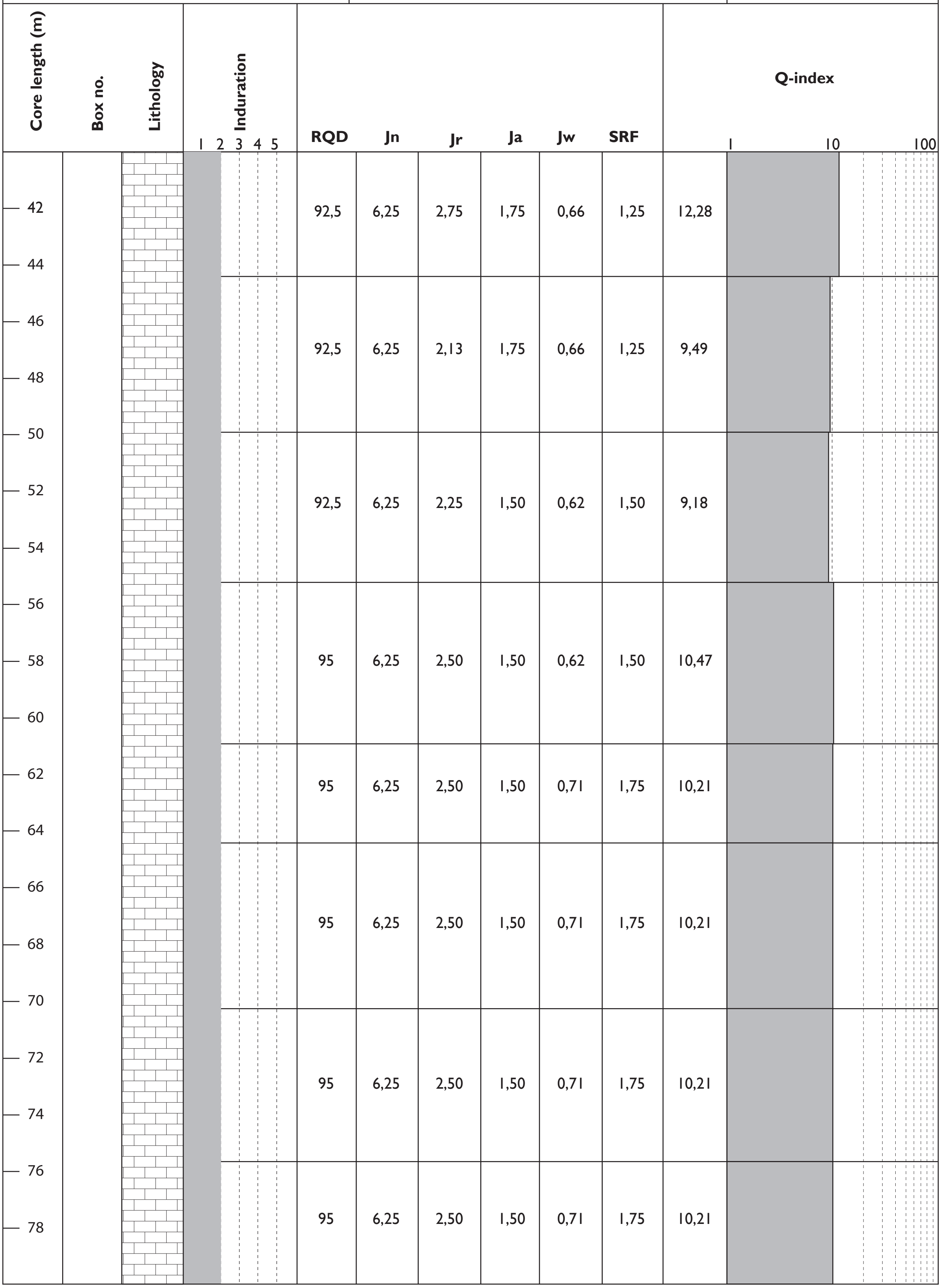
Page: 2 **of:** 3

RØRDAL 2

Rep no:

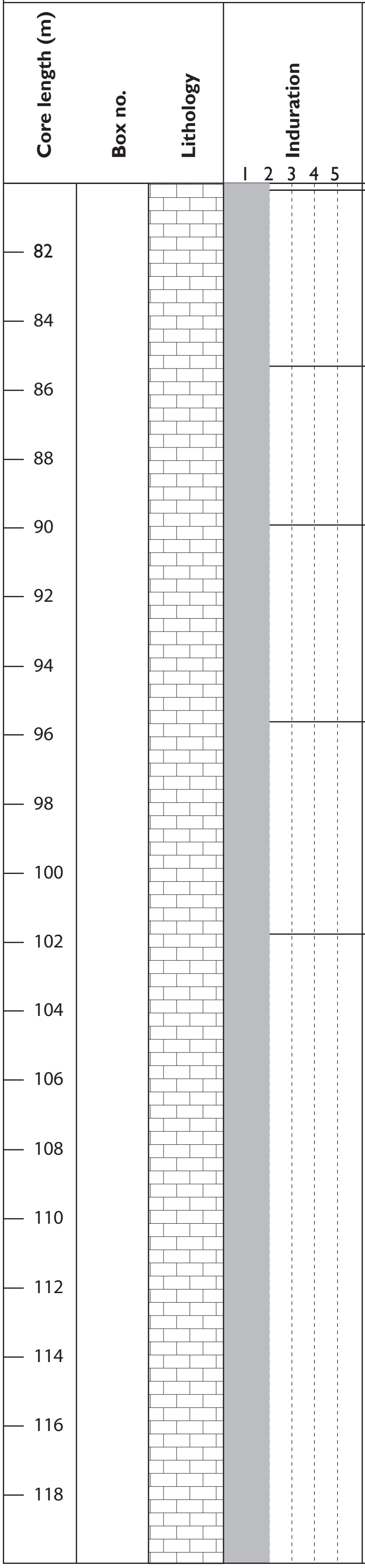
Init: PRJ/SROE

GEUS

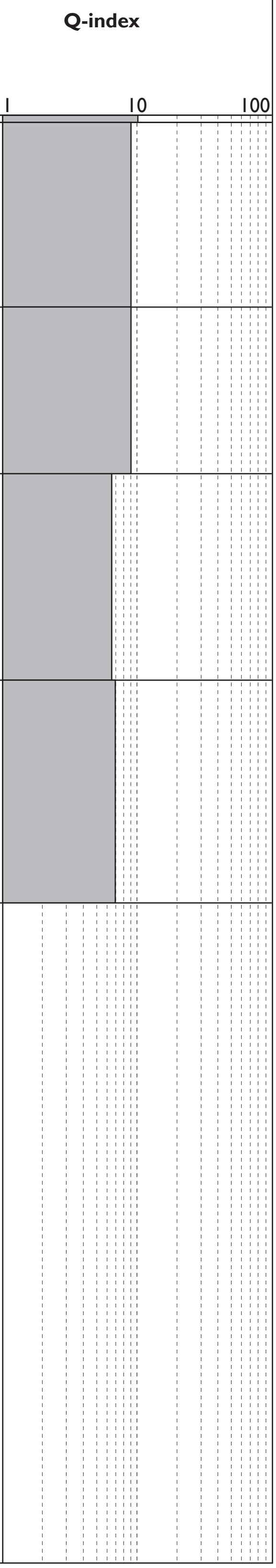


RQD	Jn	Jr	Ja	Jw	SRF	Q-index
92,5	6,25	2,75	1,75	0,66	1,25	12,28
92,5	6,25	2,13	1,75	0,66	1,25	9,49
92,5	6,25	2,25	1,50	0,62	1,50	9,18
95	6,25	2,50	1,50	0,62	1,50	10,47
95	6,25	2,50	1,50	0,71	1,75	10,21
95	6,25	2,50	1,50	0,71	1,75	10,21
95	6,25	2,50	1,50	0,71	1,75	10,21
95	6,25	2,50	1,50	0,71	1,75	10,21

Q - rating	**Page:** 3 **of:** 3	
RØRDAL 2	**Rep no:** **Init:** PRJ/SROE	G E U S



RQD	Jn	Jr	Ja	Jw	SRF	Q-index
96,25	6,25	2,50	1,50	0,71	2,00	9,05
96,25	6,25	2,50	1,50	0,71	2,00	9,05
93,75	6,25	2,50	1,50	0,71	2,75	6,41
96,25	6,25	2,50	1,50	0,71	2,75	6,58



Sveriges Geologiska Undersökning

CRYSTALLINE ROCKS FOUND LESS THAN 500 m BELOW GROUND LEVEL IN SKÅNE

2008-01-25

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Dnr: 08-154/2008

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Geological Survey of Sweden

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Ulf Sivhed

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Introduction

On commission of GEUS maps showing a brief outline of crystalline rocks found less than 500 m below ground level in Skåne are compiled. The purpose of these maps is the localisation of a cavern on the depth of 500 m in the crystalline rock. The cavern should be localised as close to Denmark as possible and also close to the sea.

Material

The presented maps are extracted from the SGU mapping programme. The used maps concerning the bedrock are in the SGU series Af in the scale 1:50 000. They are produced in the years 1978 – 2005. The soil thickness maps originates from information from the same maps and from the SGU Hydrogeological database: wells.

Background material

In order to give a brief outline of the depth crystalline rocks less than 500 m below ground level in Skåne. Six different maps are presented. One map shows the soil thickness (Quaternary deposits) while the five other shows the crystalline rocks either covered with younger sedimentary rocks or crystalline rocks outcropping or only covered with Quaternary deposits. A combination of the soil thickness map and the other maps give an approximately depth to crystalline rocks not deeper than 500 m in Skåne.

In the central Skåne there are some minor area with crystalline covered by thin (up to 50 – 60 m thick) Jurassic deposits. These areas are not marked on the maps.

Fig. 1. Map showing soil (Quaternary deposits) thickness.

Fig. 2. Map showing outcropping crystalline rocks or crystalline rocks covered with soil (Quaternary deposits).

Fig. 3. Map showing Cambrian and Ordovician rocks resting on crystalline rocks. The Cambrian and Ordovician rocks have a maximum thickness of up to 400 m. Cambrian rocks are overlained by Ordovician rocks and the Cambrian rocks rest on the crystalline basement.

Fig. 4. Map showing Jurassic rocks resting on the crystalline basement in the Ängelholm Trough. In the southern trough margin the Jurassic rocks have a thickness of around 400 m. The thickness decrease to the north and west where the Jurassic rocks pinch-out.

Fig. 5. Map showing Jurassic and Cretaceous rocks resting on the crystalline basement in the Vomb Trough. In the Vomb Trough Jurassic rocks cover the crystalline rocks. In the central and northern parts the Jurassic rocks are covered with Cretaceous rocks. The northern boundary of the trough is heavy faulted. The southern boundary is more gently faulted and in the southern part of the trough, the Jurassic rocks pich-out against the Romeleåsen crystalline ridge. In the area covered with Cretaceous rocks, the Jurassic and Cretaceous rocks have a total thickness of more than 500 m. In the

area in the south and west the total thickness of the Jurassic and Cretaceous rocks are less than 500 m pinching-out towards the north-west and south-west.

Fig. 6. Map showing Cretaceous rocks resting on the crystalline basement in the Kristianstad Basin. The Cretaceous rocks have a thickness between 10 - 300 m. The maximal thickness in the south-eastern part along a NW - SE trending axle dipping in a south-east direction.

Fig. 7. Map showing tectonic the discussed tectonic structures.

Results

If the cavern should be localised close to Denmark and also close to the coast are probably Kullen and Bjärehalvön an alternative as well as the Ängelholm Trough. At Kullen and Bjärehalvön the crystalline rocks crops out while it is covered with sedimentary rocks in the Ängelholm Trough. As the Kullen area is protected by environmental restriction it is probably problematic (impossible?) to get permission for such a construction in this area. It is probably easier to get permission in the Ängelholm Bjärehalvön area.

On the east-coast, north of Simrishamn crystalline rocks crops out. Crystalline rocks covered by up to 400m thick sedimentary rocks forms the coastline south of Simrishamn. In the near coast areas of the Kristianstad Basin the crystalline rocks are covered by an up to 300 m thick sequence of Cretaceous rocks. There are probably environmental restrictions on parts of this area.

If the construction could be located more distance from the coast, the There are many alternative in central and northern and central Skåne. The Romeleåsen and Söderåsen areas are also of interest. In this are there are quarry activities and also abandoned quarries which could be useful in the project. There are however environmental restrictions in these both areas.

Conclusion

In many parts of Skåne there are environmental restrictions especially in coastal areas.

If the construction should be located close to the coast and also close to Denmark, the Ängelholm – Bjärehalvön area is an alternative.

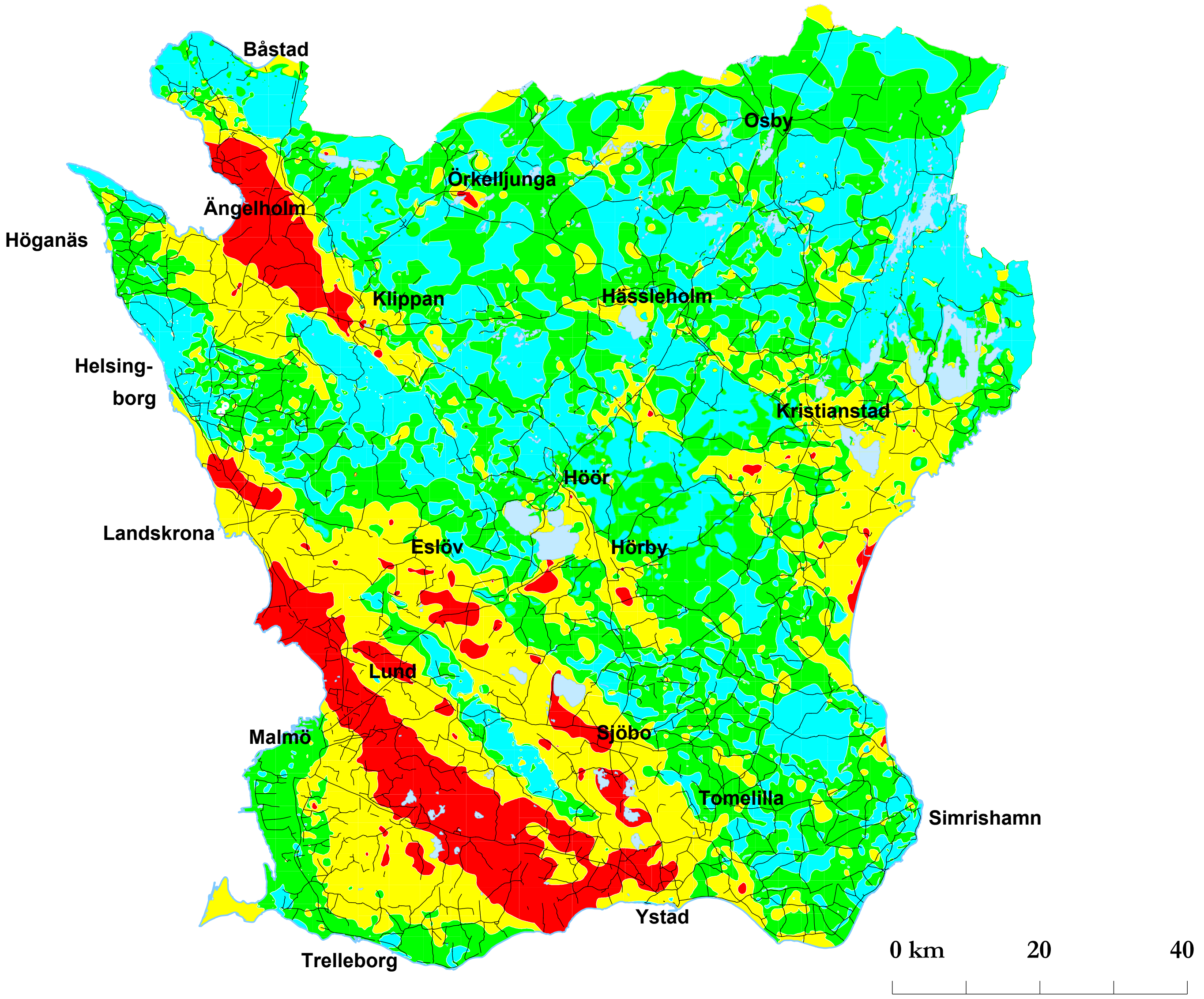
If the construction should be located close to Denmark and at certain distance from the coast, parts of the Romeleåsen and Söderåsen is an alternative.

In central and northern Skåne there are many alternatives, there is however a certain distance to Denmark.

On the east-coast, there are many alternatives. There are, however, environmental restrictions in this area.

Recommendations

When the area for location of the cavern is localised. The first step is to find out if there are some environmental or other restrictions in the area. The easiest way to start is to control the “Kommunala översiktsplaner” for the area and also contact authorities as kommun and länsstyrelse.



Soil thickness

🟦 0 - 5 m

🟩 5 - 15 m

🟨 15 - 50 m

🟥 > 50 m

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Figure 1

Crystalline rocks found less than 500 m below ground level in Skåne. Soil thickness.

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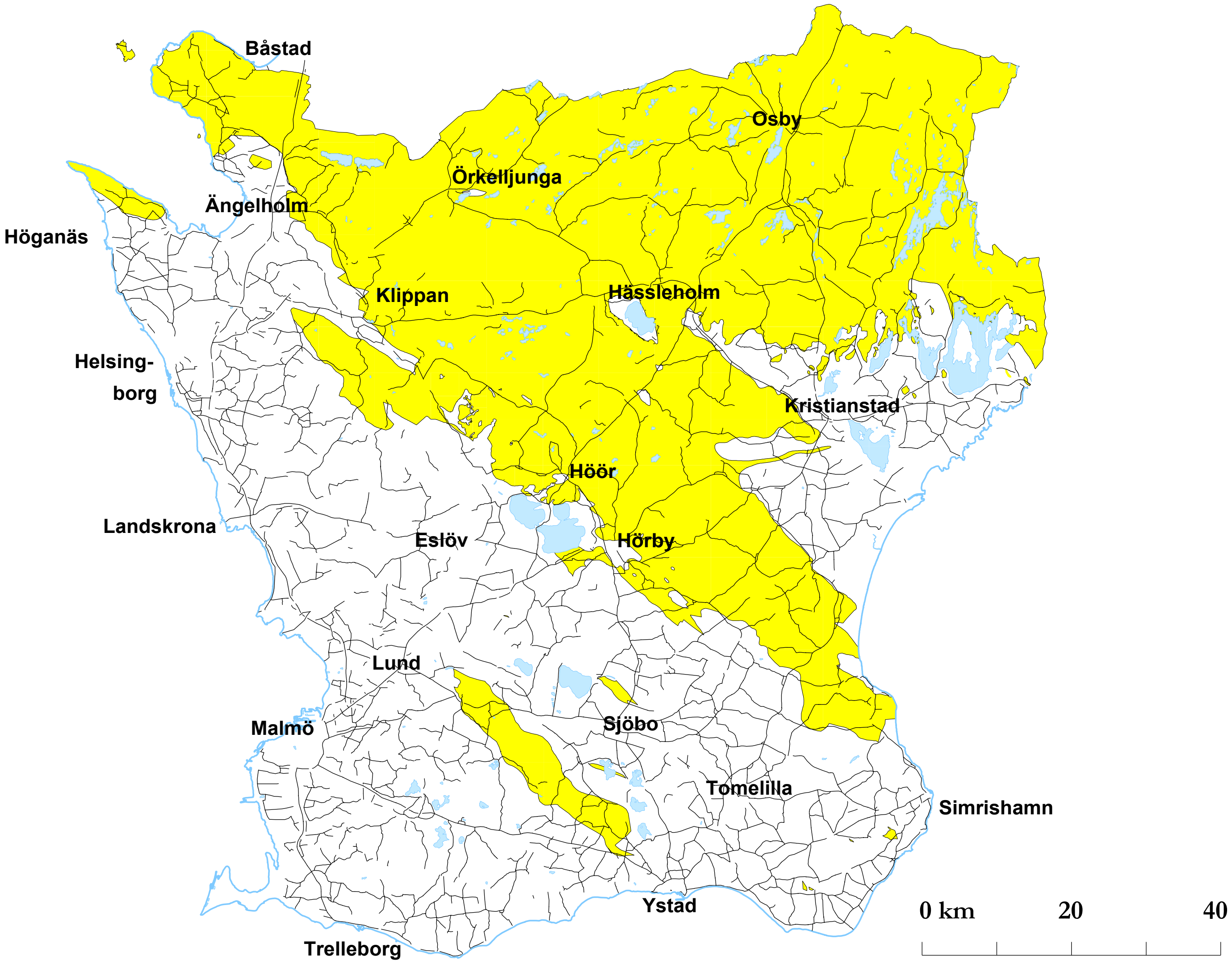

🟨 Crystalline rocks, outcropping or covered with soil

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Figure 2

Crystalline rocks found less than 500 m below ground level in Skåne. Crystalline rocks.

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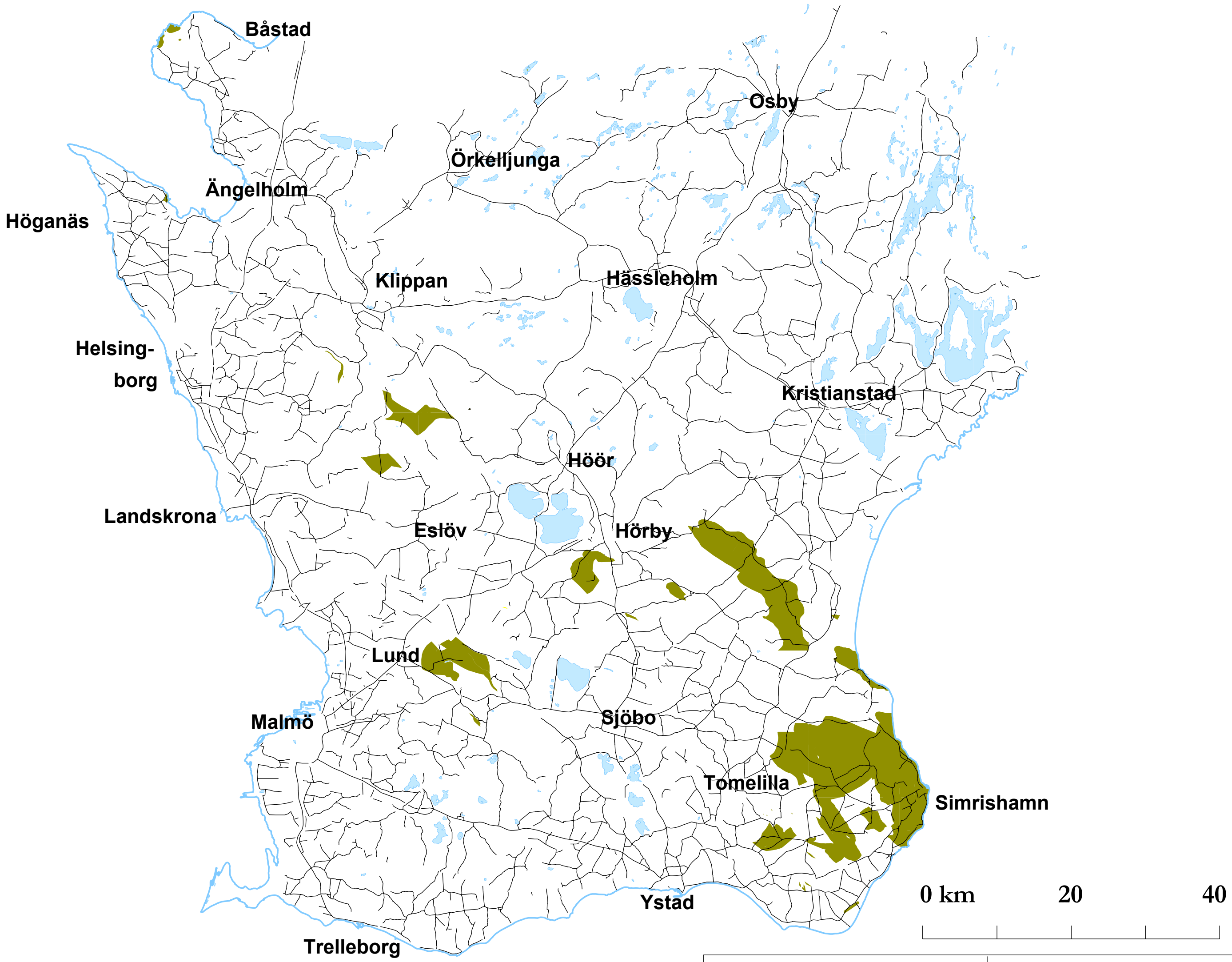

🟩 Cambrian - Ordovician rocks outcropping or covered with soil

Cambrian and Ordovician rocks have a total thickness up to 400 m. Cambrian rocks are overlained by Ordovician rocks and the Cambrian rocks rest on the crystalline basement.

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Figure 3

Crystalline rocks found less than 500 m below ground level in Skåne. Cambrian - Ordovician rocks.

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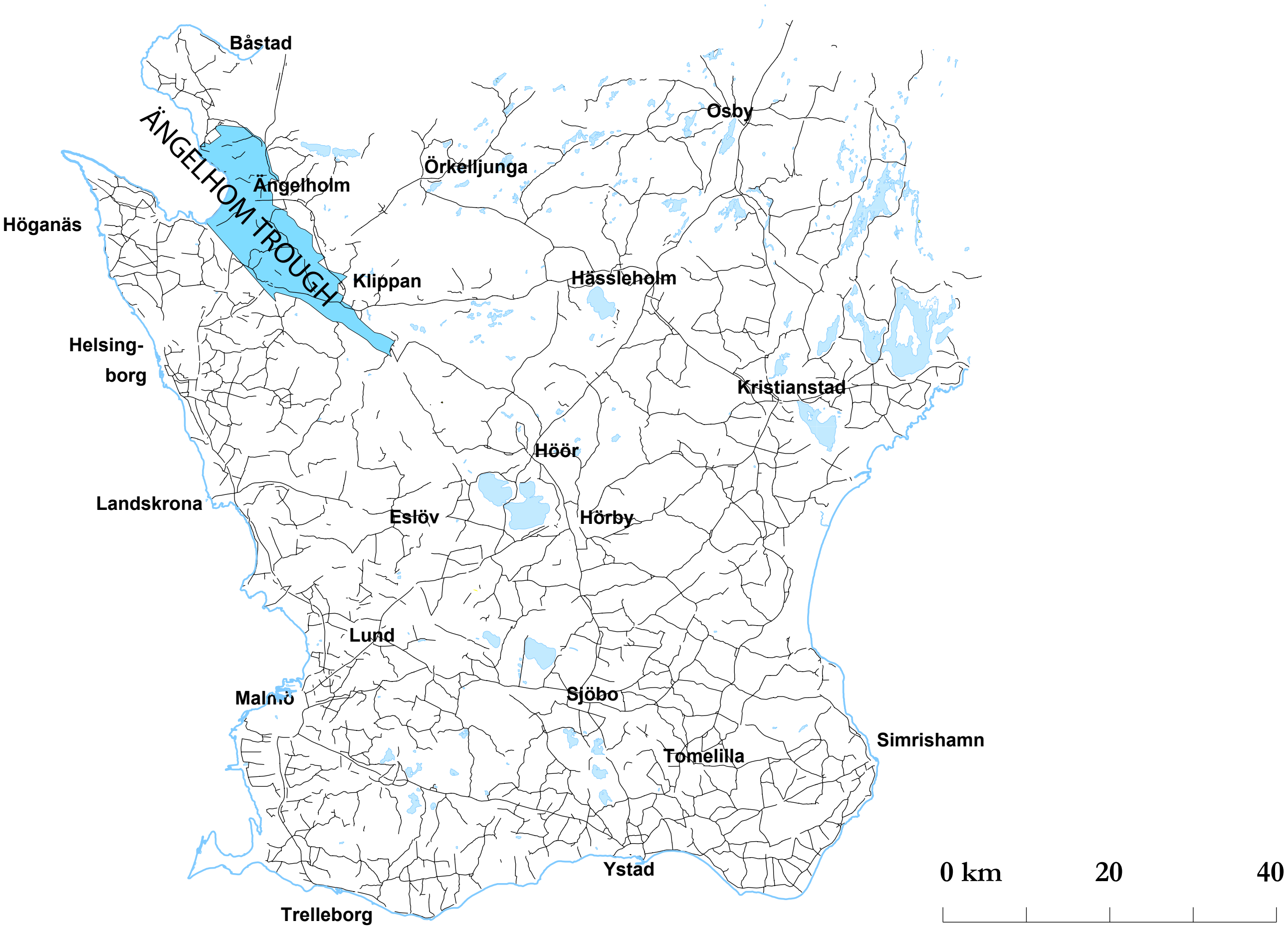

🟦 Jurassic rocks, covered with soil

In the Ängelholm Trough Jurassic rocks cover the crystalline rocks. In the southern trough margin the Jurassic rocks have a thickness of around 400 m. The thickness decrease to the north and west where the Jurassic rocks pinch-out.

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Figure 4

Crystalline rocks found less than 500 m below ground level in Skåne. Jurassic rocks, Ängelholm Trough.

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🟩 Cretacous rocks, outcropping or covered with soil

🟦 Jurassic rocks, outcropping or covered with soil

In the Vomb Trough Jurassic rocks cover the crystalline rocks. In the central and northern parts the Jurassic rocks are covered with Cretaceous rocks. The northern boundary of the trough is heavy faulted. The southern border is more gently faulted and in the southern part of the trough, the Jurassic rocks pich-out against the Romeleåsen crystalline ridge.
In the area covered with Cretaceous rocks, the Jurassic and Cretaceous rocks have a total thickness of more than 500 m.
In the area in the south and west the total thickness of the Jurassic and Cretaceous rocks are less than 500 m pinching-out towards the north-west and south-west.

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Figure 5

Crystalline rocks found less than 500 m below ground level in Skåne. Cretaceous - Jurassic rocks. Vomb Trough.

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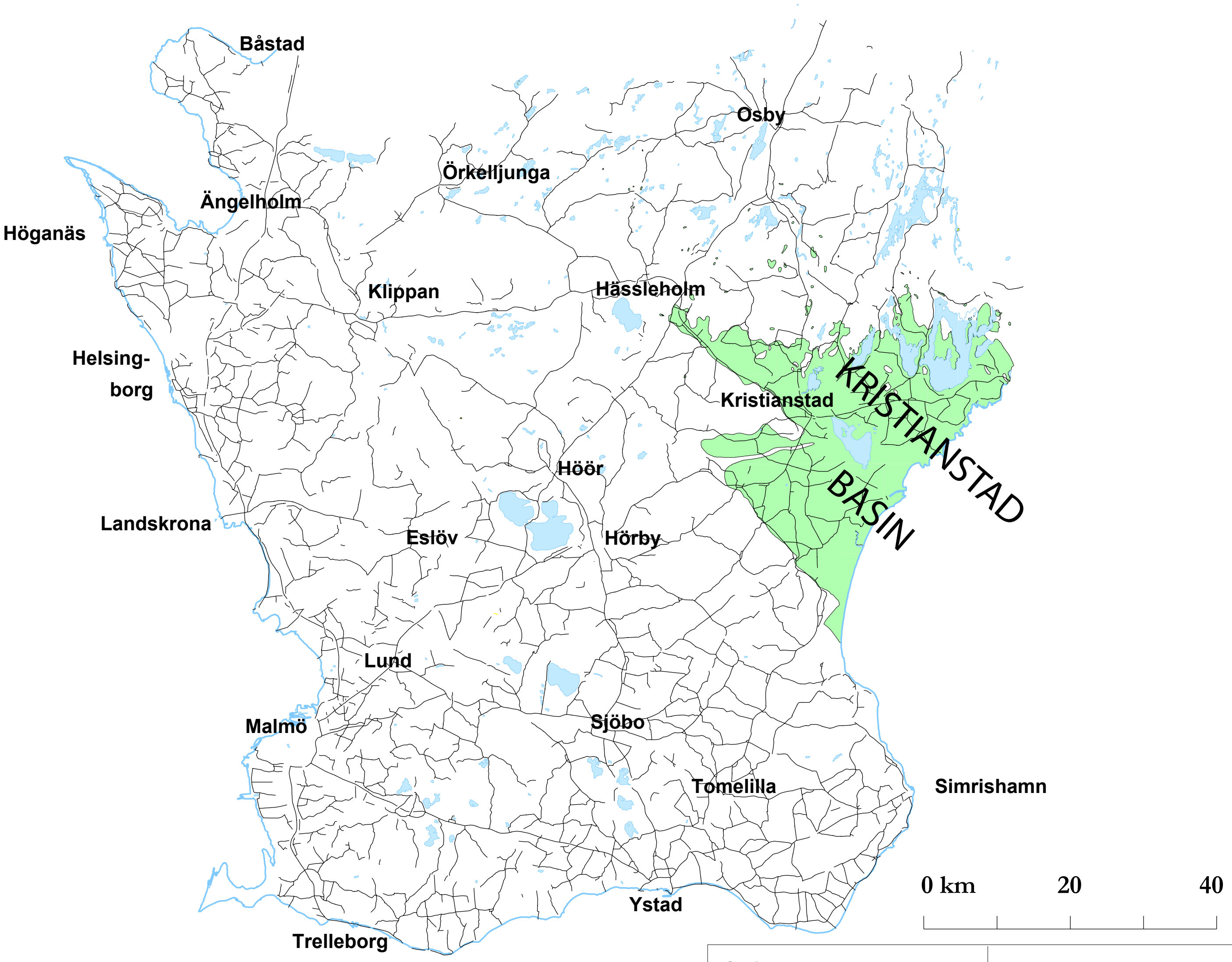

🟩 Cretacous rocks, outcropping or coverd with soil

In the Kristianstad Basin, Cretaceous rocks rest on the crystalline basement. The Cretaceous rocks have a thickness between 10 - 300 m. he maximal thickness in the south-eastern part along a NW - SE trending axle dipping in a south-east direction.

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Figure 6

Crystalline rocks found less than 500 m below ground level in Skåne. Cretaceous rocks, Kristianstad Basin.

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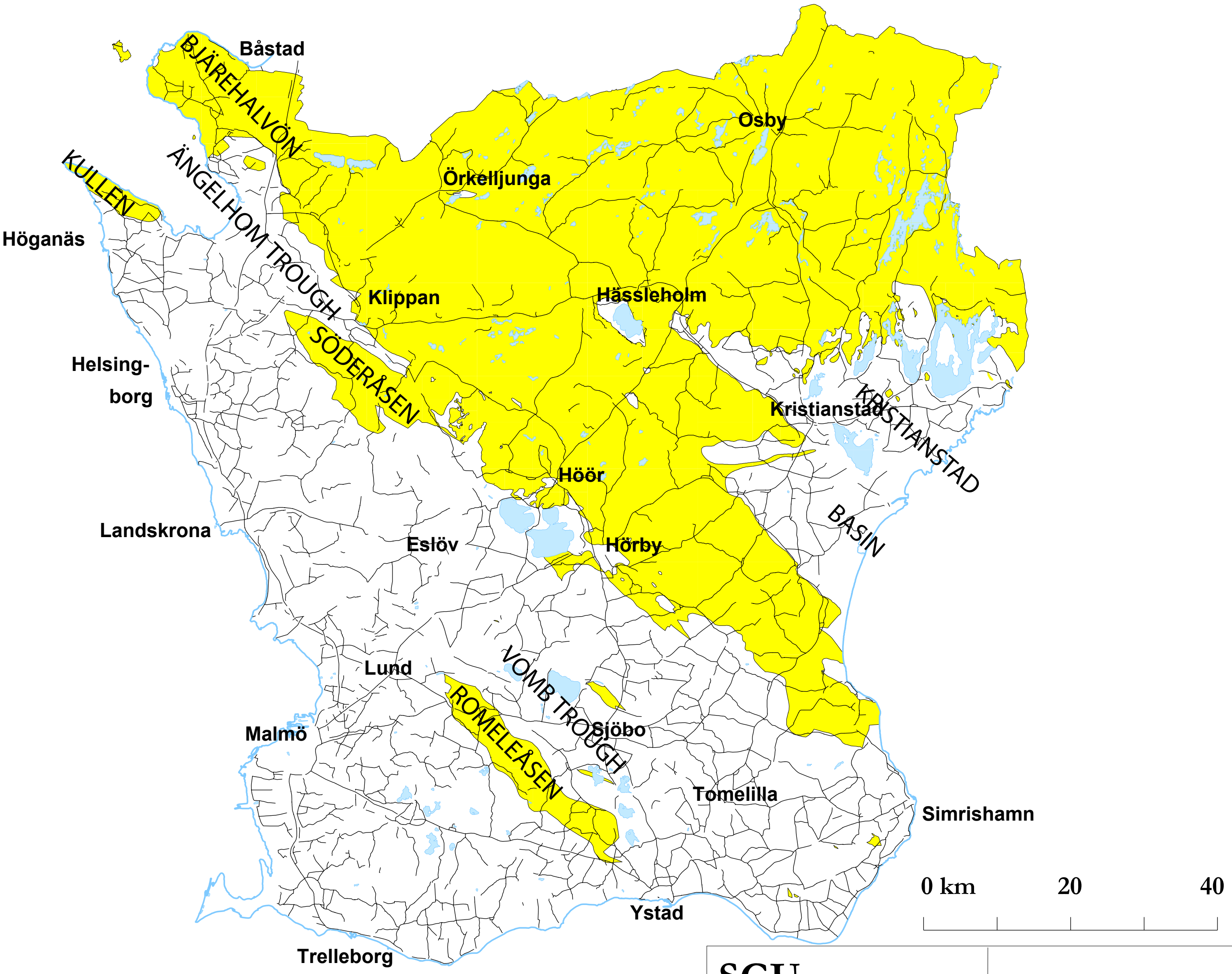

🟨	Crystalline rocks, outcropping or covered with soil
VOMB TROUGH	Tectonic structure

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Figure 7

Crystalline rocks found less than 500 m below ground level in Skåne.
Main tectonic structures.

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