DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2013/23

Source rock evaluation of Carboniferous and Permian rocks in the Ørslev-1 and Søllested-1 wells

A study carried out for New World Resources

Henrik I. Petersen

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

G E U S

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Contents

1. Introduction

This report presents a source rock evaluation of the Lower Carboniferous (Namurian) section penetrated by the Ørslev-1 well and part of the Permian (Zechstein, Z2) section penetrated by the Søllested-1 well. The study is carried out for licence 1/08 holders New World Resources (operator), Danica Resources Aps, and Nordsøfonden (Danish North Sea Fund). The source rock quality of the samples was evaluated by Source Rock Analyzer (Rock-Eval) pyrolysis, total organic carbon (TOC), total carbon (TC) and total sulphur (TS) determinations, and qualitative inspection of the kerogen by reflected white light and fluorescence-inducing blue light microscopy.

The objective of the study was to determine the petroleum generation potential and thermal maturity of the Palaeozoic deposits.

The Ørslev-1 well was drilled by DUC in 1968 on the island of Falster (Latitude: 54° 46' 55.0" North; Longitude: 11° 59' 2.0" East). The well had TD at 2574 m bkb, and penetrated 523 m (2051–2574 m bkb) of Lower Carboniferous (Namurian) silty mudstones with coaly plant remains interbedded with grey fossiliferous marine mudstones and limestones. Two cores were taken. Core 2 from 2343–2362 m consists of light grey, grey and dark grey mudstones.

The Søllested-1 well was completed by DUC in 1982 on the island of Lolland (Latitude: 54° 48' 5.0" North; Longitude: 11° 17' 55.0" East). The well had TD in the Rotliegende Group at 2702 m bkb. The Søllested-1 well penetrated 611 m of the Permian Zechstein Group from 2065–2676 m bkb. The 9 m core 1 was taken from 2587–2596 m in the Z2 unit composed of millimetre-bedded carbonate mudstone.

2. Samples and Methods

2.1 Samples

2.1.1. The Ørslev-1 well

Source rock screening data (TC, TOC, Rock-Eval) from 48 previously analysed cuttings samples from the Lower Carboniferous interval 2054.35–2517.64 m were obtained from GEUS' data-base. In addition 19 samples of dark grey mudstone were collected from the interval 2343.81–2360.23 m of core 2.

2.1.2. The Søllested-1 well

A total of 10 dark grey to blackish carbonate mudstone samples were collected from the interval 2589.01–2595.47 m of core 1.

2.2. Organic geochemical screening analyses

The content of total organic carbon (TOC, wt%), total carbon (TC, wt.%) and total sulphur (TS, wt%) in the core samples was determined by combustion in a LECO CS-200 induction furnace. For TOC determination carbonate-bonded carbon was removed by HCl treatment before combustion. The samples were pyrolyzed in a Humble Instruments and Services Source Rock Analyzer (SRA) system that yields similar data as the Rock-Eval instrument: S_1, free hydrocarbons in the sample; S_2, hydrocarbons generated by decomposition of the kerogen; T_{max}, temperature at maximum S_2 generation. The Hydrogen Index (HI) [S_2/TOC x 100) and the Production Index (PI) [S_1/S_1+S_2] were calculated. The screening data of the Namurian cuttings and core samples from the Ørslev-1 well are shown in Tables 1 and 2. The screening data from the Permian Z2 unit in the Søllested-1 well is shown in Table 3.

2.3. Organic petrography

Based on the screening data of the core samples, two samples from the Ørslev-1 well and one sample from the Søllested-1 well were selected for qualitative organic petrographic inspection of the kerogen. Pellets suited for reflected light microscopy were prepared. The core material was lightly crushed and sieved between 63 µm and 1 mm, and an appropriate analysis fraction was embedded in epoxy. The epoxy block was ground and polished to obtain a smooth surface suited for incident light microscopy and oil immersion.

2.3.1. Kerogen description

The organic geochemical analyses revealed a very low TOC content in the samples, and therefore only a qualitative description of the kerogen in the core samples was undertaken in reflected white light and fluorescence-inducing blue light using a Zeiss microscope. Huminite, inertinite and liptinite maceral identifications followed the standards and descriptions outlined in Taylor et al. (1998), ICCP (2001) and Sýkorová et al. (2005).

2.3.2. Vitrinite reflectance measurements

Vitrinite reflectance (VR) values for the Ørslev-1 well were obtained from GEUS' data-base (Table 4). The VR measurements (random) were carried out with a reflected light Zeiss photomicroscope equipped with a photomultiplier (MP 03) and a 40x Epi-Pol oil immersion objective. The photomultiplier was calibrated against a glass standard (SF11) with a reflectance of 0.69%R_o, and the measurements were conducted at 546 nm. Average VR values were calculated from selected VR populations considered to represent the indigenous vitrinite.

Seven VR values from readings on six cuttings samples and one core sample were available from the Lower Carboniferous (Table 4). The average VR values are based on 12 to 50 readings. In order to validate and constrain the VR values from the Lower Carboniferous samples, seven VR values from the Upper Permian, Upper Triassic and Lower Jurassic were included (Table 4). These measurements were carried out on cuttings samples, and the average VR values are based on 6 to 106 readings. The inclusion of all 14 VR measurements was used to construct a VR gradient for the Ørslev-1 well.

3. Results and Discussion

3.1. The Lower Carboniferous section in the Ørslev-1 well

The TOC content of the cuttings samples range from 0.04–0.72 wt.%, with an average of only 0.28 wt.% (Table 1). The content shows a general increase with depth (Fig. 1). The TC content is considerably higher, reaching a maximum content of 9.60 wt.% and with an average of 5.91 wt.%. This pattern is largely repeated by the core samples (Table 2), although the cuttings samples display a greater range in the measured TC and TOC contents. The TOC content of the core samples range from 0.53–1.00 wt.%, with an average of 0.74 wt.%, and the TOC content is thus higher than recorded in the cuttings samples (Fig. 1). The difference in the values from the two sample types can be explained by: (1) The nature of cuttings samples have an inherited potential to introduce a greater uncertainty in the measurements. This is because cuttings cover an interval (normally ~3 m to ~10 m) and thus may include different lithologies, and they may furthermore be contaminated, for example by cavings; (2) The cuttings samples cover a greater depth interval in the Ørslev-1 well, approximately 463 m, and it is thus likely that the analysed samples represent a larger lithological variation. In contrast represent the core samples largely the same mudstone lithology. However, both sample sets reveal a low TOC content, whereas the considerable difference in TC and TOC content shows that the samples are highly calcareous (Tables 1 and 2).

Organic petrography reveals that most of the TOC is derived from scarce dispersed organic matter composed of detrital particles of vitrinite and inertinite, that occur in a silty and calcareous mineral matrix (Fig. 2A). Scattered yellowish fluorescing liptinite particles are observed, and these have mainly a terrigenous origin, such as sporinite (Fig. 2B,C). Alginite may possibly be present (Fig. 2D).

The TS content in the core samples varies from 0.45–3.53 wt.% and averages 1.78 wt.% (Table 2). Framboidal pyrite in the samples suggests that most of the sulphur occurs in pyrite (Fig. 2E,F) The proportion of TS relative to TOC (TS versus TOC plot; Fig. 3) indicates a marine depositional environment, and this is further emphasised by TOC/TS ratios <1 (Table 2; Fig. 4) (Berner and Raiswell, 1984).

The T_{max} values of the core samples range from 427–440°C, corresponding to thermally immature to early mature kerogen (Peters, 1986; Bordenave et al., 1993), but T_{max} is affected by both kerogen type and a low content of TOC (less than 0.5 wt.%), the latter because of adsorption of the pyrolyzate (S_2 yields) by the mineral matrix (Peters, 1986). The average T_{max} value of the core samples is 433°C, indicating thermal immaturity. The thermal maturity (immature to marginally mature) is supported by low PI values, ranging from 0–0.25 and with an average of 0.11 (Table 2). The PI generally increases from approximately 0.1 to 0.4–0.6 from the onset of oil generation and through the oil window (Bordenave et al., 1993; Peters and Cassa, 1994). The T_{max} values from the cuttings samples are less usefull (Table 1). Several values are unrealistically low (marked by grey in Table 1) and a number of samples yield no T_{max} value at all. This can be explained by generally low S_2 pyrolysis yields and thus the absence of a well-defined S_2-peak in the pyrograms. Reliable T_{max} values derived from the cuttings are largely similar to the values obtained from the core samples. Very high PI values, corresponding to levels recorded in reservoirs, is an artefact caused by both low S_1 and S_2 yields (Tables 1 and 2).

The thermal maturity is generally confirmed by the VR values (Table 4) (Thomsen et al., 1983). The VR values of the Lower Carboniferous samples range from 0.57–0.67%R_o, suggesting thermal immaturity to marginally mature if the start of the oil window is set at a VR of 0.6%R_o. The present burial depth of the samples does not correspond to maximum burial depth because of exhumation. This is emphasised by the constructed VR gradient using present day depths (Fig. 5). The VR gradient intercepts the surface close to 0.40%R_o, which is a too high reflectance value for peaty organic matter unaffected by burial. Recorded reflectance values of peaty organic matter at the surface range from 0.1–0.25%R_o (Cohen et al., 1987). Present day depths of the Ørslev-1 well were therefore corrected for a net-exhumation of 362 m based on chalk velocities (Japsen and Bidstrup, 1999), and the VR values were plotted against the chalk-velocity corrected depths (Fig. 6; Table 4). This improves the VR gradient slightly, but it still intercepts the surface at a too high VR value. Two explanations are plausible: (1) The depth-correction based on chalk sonic velocities underestimate the magnitude of exhumation, (2) The calculated VR values for the Upper Permian, Upper Triassic and Lower Jurassic samples are too high. Lower average values would yield a steeper gradient that would intercept the surface at a lower VR value. This latter explanation appears reasonable. Average VR values >0.4%R_o at depths (corrected) of approximately 900–1000 m are higher than normally recorded at similar depths in wells in the Danish-Norwegian Basin (Petersen et al., 2008).

The petroleum generation potential of the Lower Carboniferous is negligible (Tables 1 and 2). S_2 pyrolysis yields from the cuttings samples range from nil to 0.64 mg HC/g rock, with an average of 0.19 mg HC/g rock, whereas S_2 yields from the core samples range from 0.05–0.36 mg HC/g rock, with an average of 0.17 mg HC/g rock. Combined with the low TOC content the samples are mainly classified as poor source rocks with no potential (Fig. 7). Very low to low HI values throughout the Lower Carboniferous furthermore underlines the non-generative potential of the deposits (Fig. 8). Only one cuttings sample at 2453.64 m has a high HI value (Fig. 8; Table 1), but this value is probably an artefact derived from a low S_2 yield and a very low TOC content. The average HI of the cuttings samples (excluding the high value) is only 65 mg HC/g TOC. The HI of the core samples range from only 8–37 mg HC/g TOC, with an average of 22 mg HC/g TOC. Plotted in the HI versus T_{max} diagram the organic matter in the samples corresponds to Type IV kerogen having no source rock potential (Fig. 9). It is noticeable that the determined source rock quality largely corresponds to the initial generation potential of the samples because of their low thermal maturity.

Organic petrography has, however, revealed the possible presence of solid bitumen in the core sample from 2355.19 m depth (present day) (Fig. 2G). It is difficult to determine whether these particles are solid bitumen or resinite derived from higher land plants. The particles are characterised by being dark (low reflectance) in white reflected light and orange fluorescing in blue light excitation. The morphological appearance of the particles may suggest that they are solid bitumen. Bitumen is the initial heavy petroleum generated from source rocks, and as the maturity data indicate that the lower part of the Lower Carboniferous is marginally mature this is possible. The source rock quality indicates, however, that the bitumen must have been generated from very restricted, locally enriched levels in the mudstones.

3.2. The Zechstein (Z2) section in core 1, Søllested-1 well

The TOC content of the Z2 core samples range from 0.04–0.21 wt.%, with an average of only 0.09 wt.% (Table 3). The TC content is significantly higher (average 11.33 wt.%) in agreement with the carbonate mudstone lithology of the cored section.

Organic petrography shows that the TOC is derived from very little dispersed organic matter in the calcareous mineral matrix. The dispersed organic matter includes tiny vitrinite particles and probably alginite (Fig. 10).

The TS content in the core samples varies from 0.05–0.45 wt.% and averages 0.20 wt.% (Table 3). Some pyrite, including framboidal form, has been observed by microscopy, and the sulphur may be related to this. The TOC/TS ratio is low, ranging from 0.26–0.90 (average 0.51) corresponding to a marine depositional environment (Fig. 11) (Berner and Raiswell, 1984).

The T_{max} values range from 426–433°C and averages 429°C. This shows that the kerogen is thermally immature as the start of the oil window corresponds to a T_{max} of 435°C (Peters, 1986; Bordenave et al., 1993). High to very high PI values in the majority of the samples is likely an artefact caused by very low to low S_1 and S_2 yields (Table 3). The PI values are thus not considered a reliable maturity parameter for these samples.

The petroleum generation potential of the Z2 samples is poor (Table 3). S_2 pyrolysis yields range from 0.02–0.31 mg HC/g rock, with an average of only 0.11 mg HC/g rock. Due to the low S_2 yields and TOC contents most of the samples will plot outside the S_2 versus TOC diagram. Only four samples will fall inside the plot, and these indicate poor source rock quality (Fig. 12). The HI values range from 32–181 mg HC/g TOC and averages 110 mg HC/g TOC (Table 3). However, most of these values are based on low S_2 yields and TOC contents as described above. The HI values predict non-generative to gas-prone source rocks (Fig. 13). The HI versus T_{max} diagram furthermore suggests that the organic matter in the samples corresponds to Types III to IV kerogen. Because of the thermal immaturity of the samples, the determined source rock quality corresponds to the initial generation potential of the samples.

Efficient Permian source rocks have, however, been documented by the oil in the Løgumkloster-1 well drilled in southern Jutland, Denmark. The biomarker characteristics of the oil indicate that it was derived from a carbonate/marly source rock which was deposited under high salinity conditions, and which received very minor amounts of higher land plant terrestrial organic matter. The biomarker characteristics include *inter alia a* low Pr/Ph ratio of ~0.5, abundance of 30-norhopanes, absence of 28,30-bisnorhopane, a high proportion of homohopanes above C_{31}, presence of gammacerane, a moderate diasterane/regular sterane ratio, and a high proportion of αββ-steranes. This biomarker composition is similar to, but not identical to, the composition of oil shows sourced from Permian rocks in wells in the Outer Rough Basin, Danish Central Graben (Petersen et al., 2010).

4. Conclusion

The Lower Carboniferous section in the Ørslev-1 well consists of calcareous mudstones deposited in a marine environment. The TOC content is generally low and consists of minor amounts of dispersed vitrinite and inertinite and scattered yellowish fluorescing liptinite particles, mainly of terrigenous origin. The kerogen can be characterised as overall Type IV. Maturity parameters (VR, T_{max}, PI) indicate that the Lower Carboniferous deposits are thermally immature to marginally mature. Source rock data indicate non to poor petroleum generation potential. The possible presence of solid bitumen (early generated heavy petroleum) may indicate generation from very restricted, locally enriched levels in the mudstones. Generally, however, the analysed samples do not imply that the Lower Carboniferous calcareous mudstones constitute a potential source rock.

The Zechstein (Z2) samples from the Søllested-1 well are composed of carbonate mudstones deposited in a marine environment. The TOC content is very low, and the organic matter is composed of tiny vitrinite particles and possibly alginite. The organic matter corresponds to Type III and IV kerogen. The cored section is thermally immature. The source rock quality is poor, indicating a potential for gas generation at the best.

5. References

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6. Figure and Table Captions

Fig. 1. Variation in TOC content in the Lower Carboniferous section of the Ørslev-1 well. Insert shows the TOC variation in the samples from core 2.

Fig. 2. Photomicrographs in oil immersion of macerals in two core samples from the Ørslev-1 well. A1, E, F, G1 shown in white reflected light, A2, B–D, G2 shown in fluorescence-inducing blue light. **A1, A2**: Small dispersed vitrinite and inertinite particles (non-fluorescing) in a weakly yellowish fluorescing silty (and calcareous) mineral matrix (sample 23324: 2345.82 m). **B–D**: Fluorescing sporinite and probably alginite. Orange fluorescing solid bitumen may be present (B: sample 23333, 2355.19 m; C, D: sample 23324, 2345.82 m). **E, F**: Framboidal pyrite (syngenetic) and small inertinite particles (sample 23333: 2355.19 m). **G1, G2**: Large orange fluorescing particle (sample 23333: 2355.19 m). The particle has similarity with resinite, but it is likely solid bitumen. This is based on comparison with other observed particles having similar reflectance and fluorescence, but showing a morphology not usually associated with resinite (e.g. particle shown in B).

Fig. 3. TS versus TOC plot of the core samples from the Ørslev-1 well indicating a marine depositional environment. Plot from Berner and Raiswell (1984).

Fig. 4. TOC/TS versus TOC plot of the core samples from the Ørslev-1 well. Very low TOC/TS ratios indicate a marine depositional environment. TOC/TS boundaries from Berner and Raiswell (1984).

Fig. 5. Vitrinite reflectance (VR) values plotted against present day depth, Ørslev-1 well. The boundary of the Lower Carboniferous is shown. The VR gradient intercepts the surface at a VR value close to 0.40%R_o indicating that the strata are not *in situ* (have been uplifted).

Fig. 6. Vitrinite reflectance (VR) values plotted against depths corrected for 362 m net-exhumation based of chalk sonic velocities (Japsen and Bidstrup, 1999). The VR gradient is slightly improved, but the predicted VR value at the surface is still too high for peaty organic matter (see text for discussion). The VR curve indicates that the Lower Carboniferous strata have been buried to >2400 m.

Fig. 7. S_2 versus TOC plot of the core and cuttings samples from the Ørslev-1 well. The plot shows that the source rock quality of the calcareous mudstones can be classified as poor to fair.

Fig. 8. Variation in the Hydrogen Index (HI) in the Lower Carboniferous section of the Ørslev-1 well. Insert shows the HI variation in the samples from core 2. The HI values predict absence of a petroleum generation potential.

Fig. 9. Hydrogen Index (HI) versus T_{max} plot of the samples from the Ørslev-1 well. The kerogen is mainly classified as Type IV. The high HI value of sample from 2453.64 m depth is an artefact derived from low S_2 yields and a very low TOC content.

Fig. 10. Photomicrographs in oil immersion of macerals in core sample 23314 (2593.80 m) from the Søllested-1 well. A shown in white reflected light, B shown in fluorescence-inducing blue light. **A** Tiny vitrinite particle in a matrix of carbonate. **B** Yellow fluorescing alginite particle in carbonate.

Fig. 11. TOC/TS versus TOC plot of the core samples from the Søllested-1 well. Very low TOC/TS ratios indicate a marine depositional environment. TOC/TS boundaries from Berner and Raiswell (1984).

Fig. 12. S_2 versus TOC plot of core samples from the Søllested-1 well. Only four samples with S_2 yields and TOC contents above 0.1 have been plotted. The plot shows that the source rock quality of the Z2 carbonate mudstones can be classified as poor.

Fig. 13. Hydrogen Index (HI) versus T_{max} plot of the core samples from the Søllested-1 well. The kerogen is classified as Type III and Type IV. The HI values predict that a gas generation potential may be present in some of the samples.

Table 1. Source rock data (cuttings) of the Lower Carboniferous section in the Ørslev-1 well.

Table 2. Source rock data of the Lower Carboniferous core samples, core 2, Ørslev-1 well.

Table 3. Source rock data of the Zechstein (Z2) core samples, core 1, Søllested-1 well.

Table 4. Vitrinite reflectance (random) values from the Ørslev-1 well.

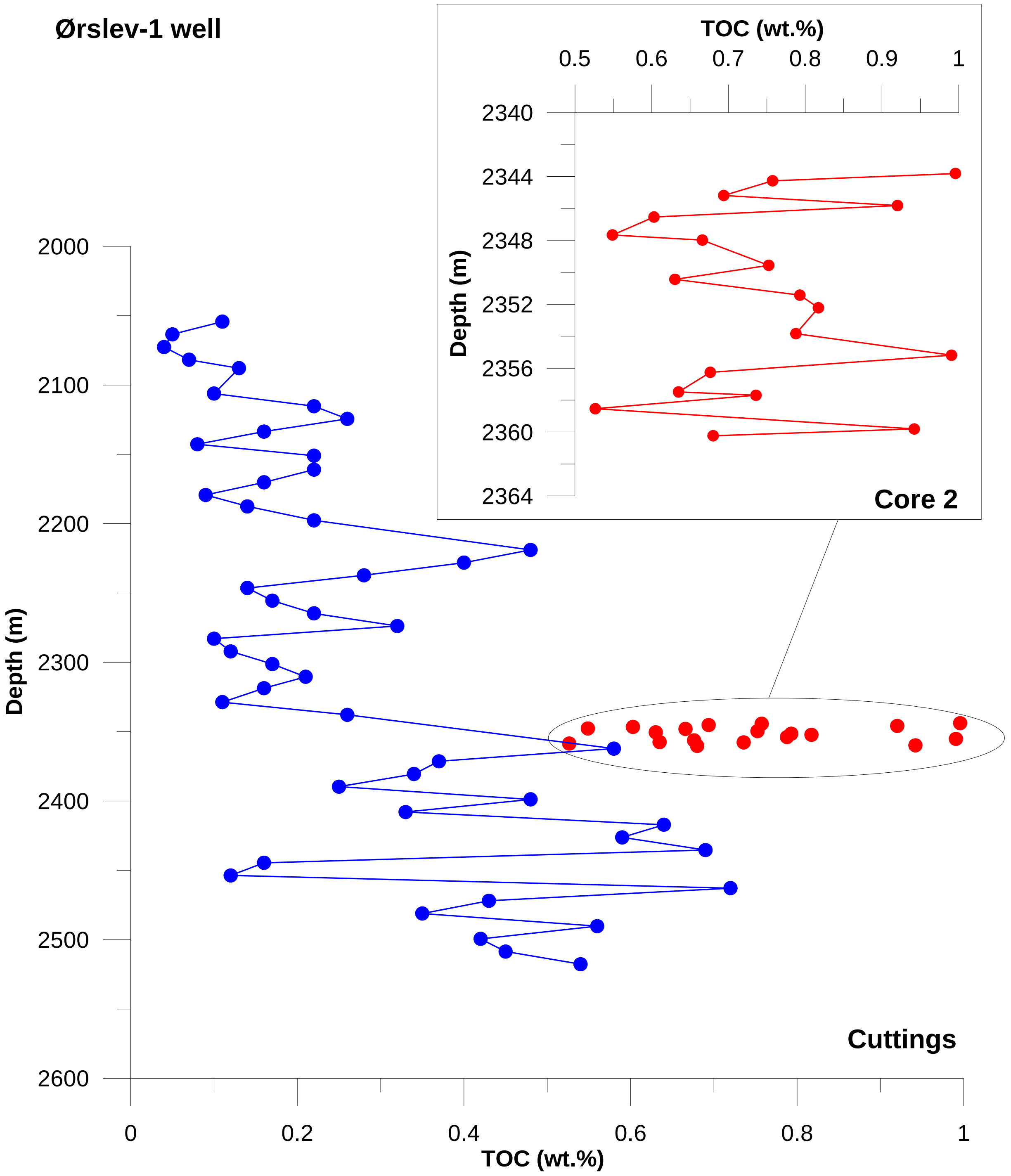
Ørslev-1 well
TOC (wt.%)
0.5
0.6
0.7
0.8
0.9
1
2340
2344
2348
2352
2356
2360
2364
Depth (m)
Core 2
2000
2100
2200
2300
2400
2500
2600
Depth (m)
Cuttings
0
0.2
0.4
0.6
0.8
1
TOC (wt.%)

Figure 1

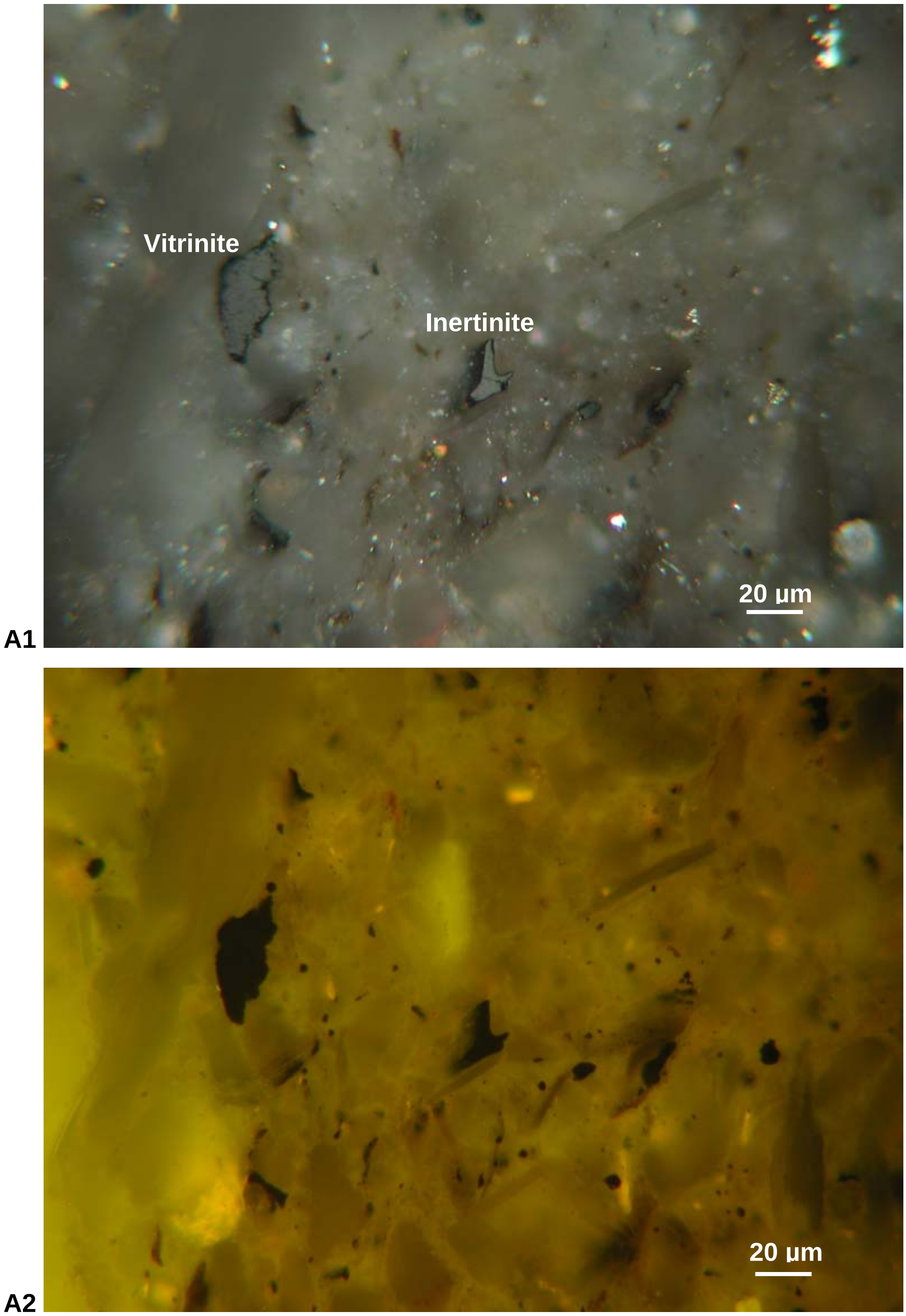

Figure 2

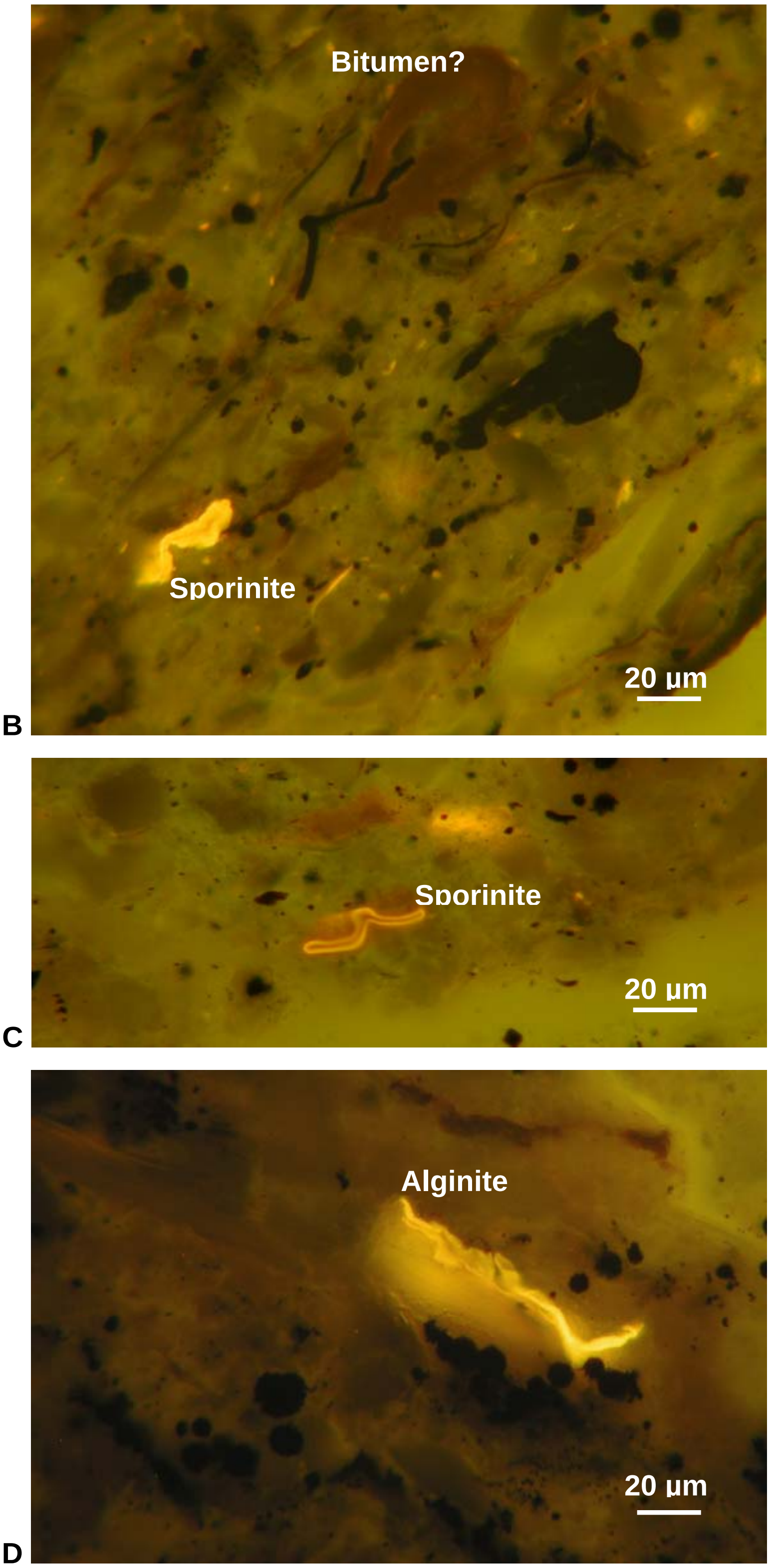

Figure 2 (continued)

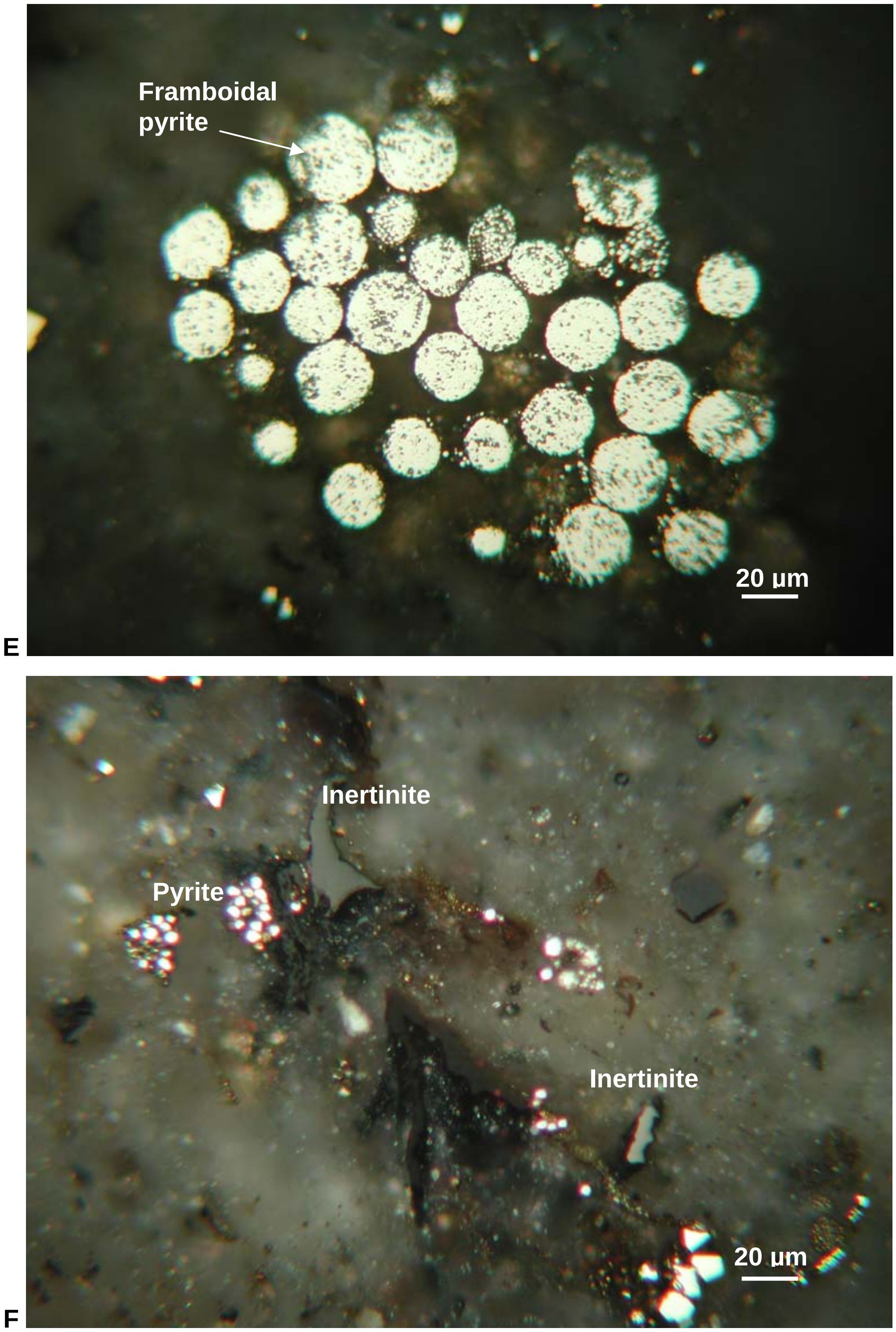

Figure 2 (continued)

G1

G2

Figure 2 (continued)

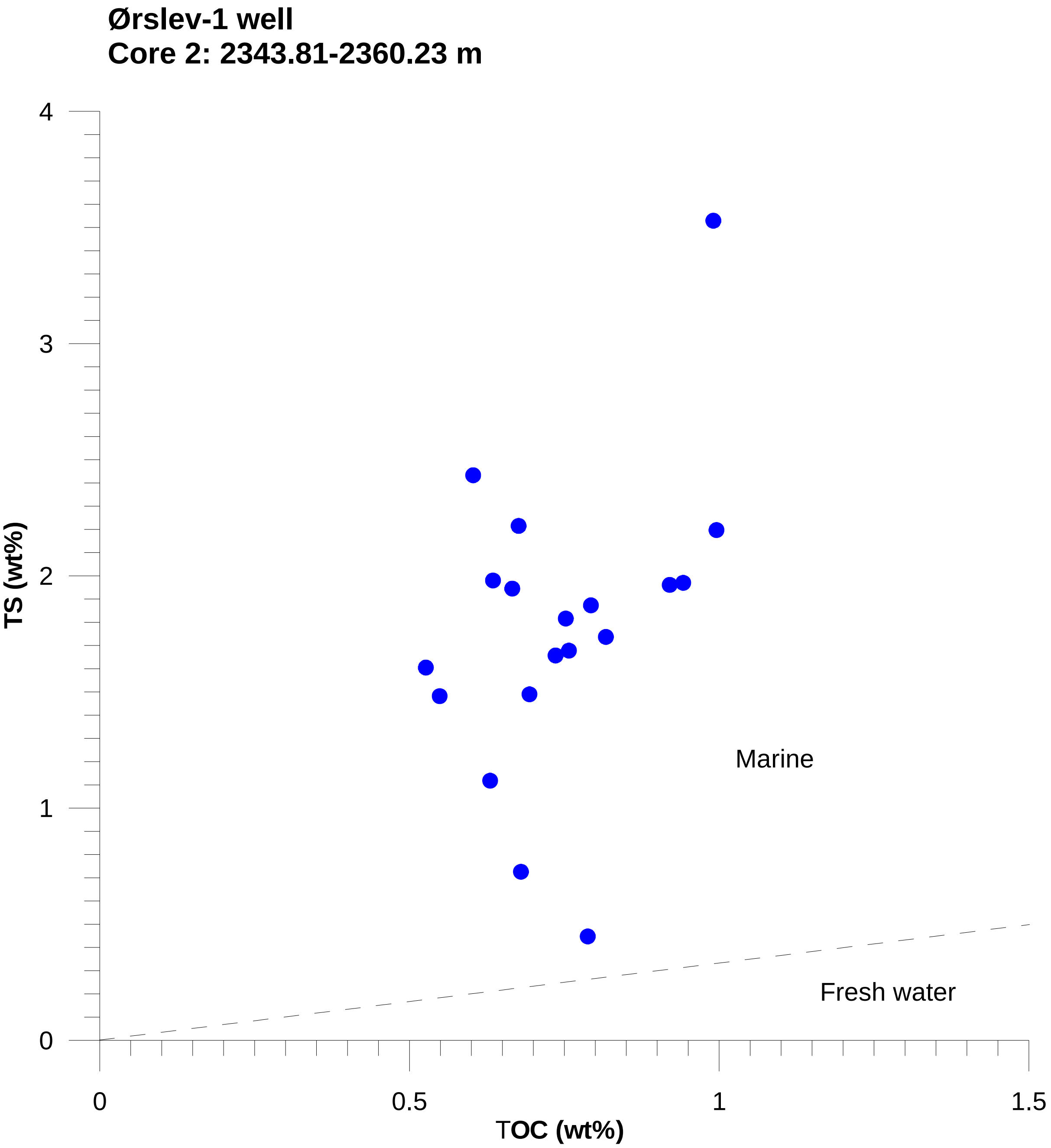
Ørslev-1 well
Core 2: 2343.81-2360.23 m
4
3
2
1
0
TS (wt%)
Marine
Fresh water
0
0.5
1
1.5
TOC (wt%)

Figure 3

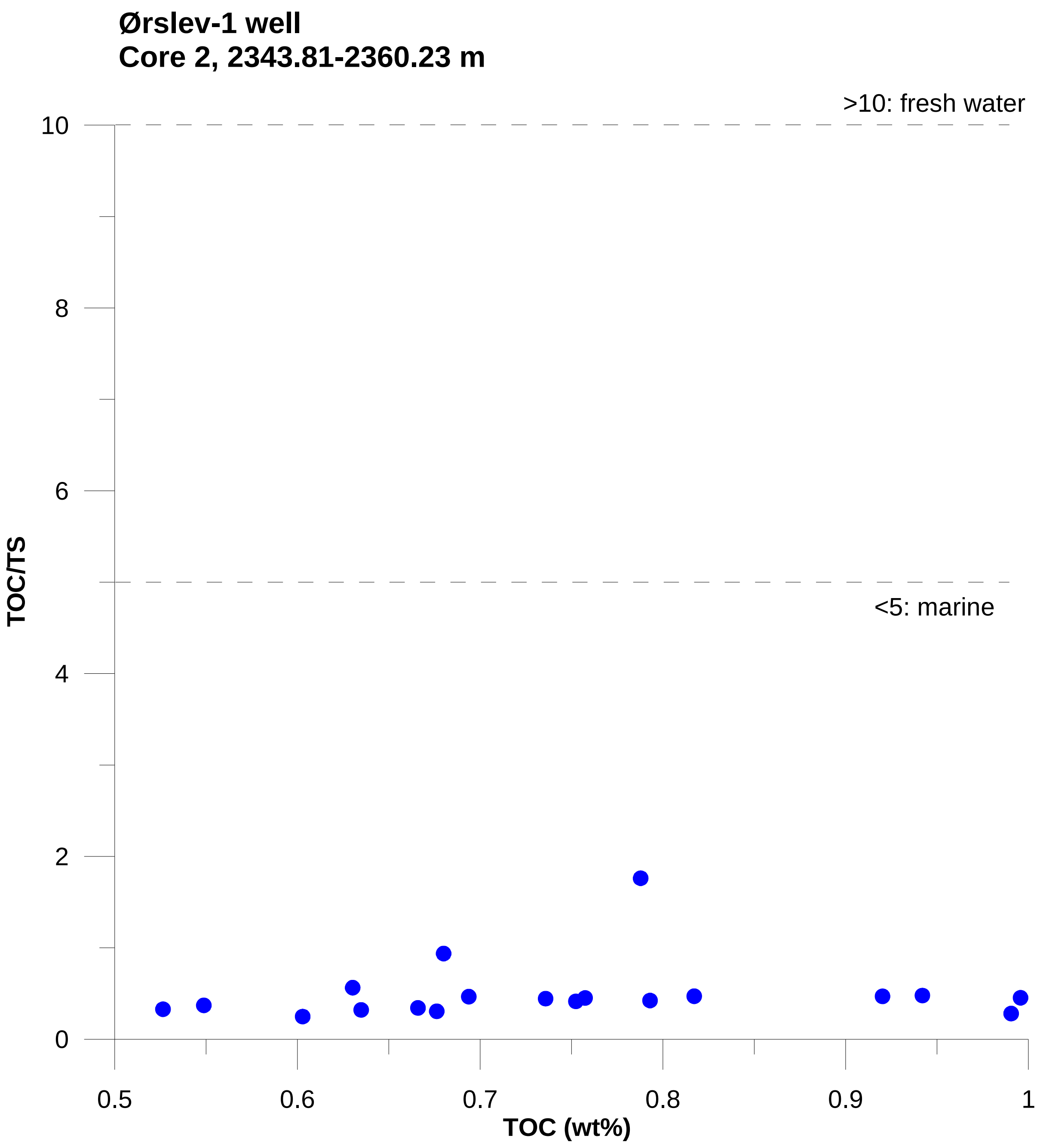
Ørslev-1 well
Core 2, 2343.81-2360.23 m
>10: fresh water
<5: marine
TOC/TS
TOC (wt%)
0
2
4
6
8
10
0.5
0.6
0.7
0.8
0.9
1

Figure 4

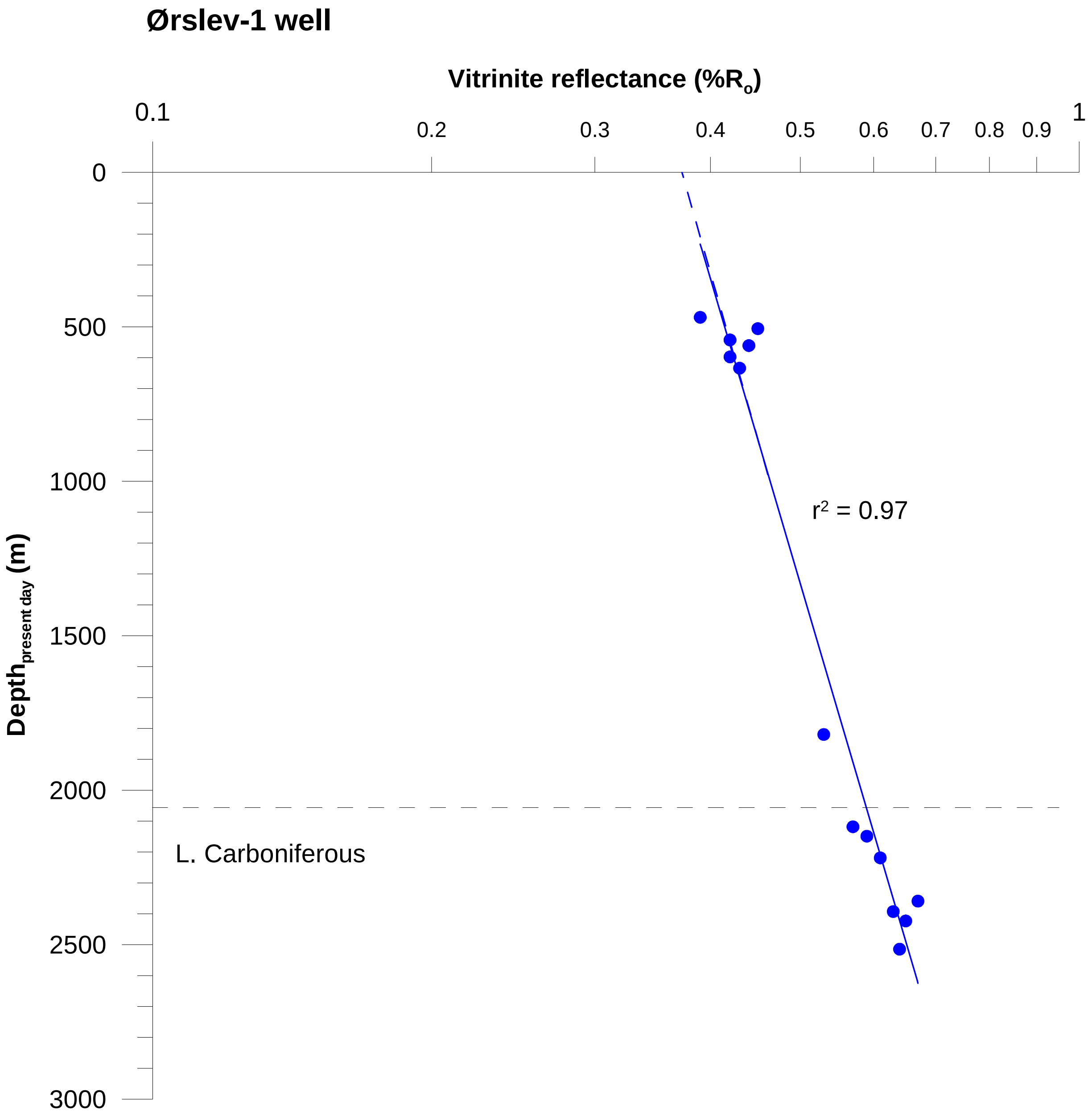
Ørslev-1 well
Vitrinite reflectance (%Ro)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Depthpresent day (m)
0
500
1000
1500
2000
2500
3000
r² = 0.97
L. Carboniferous

Figure 5

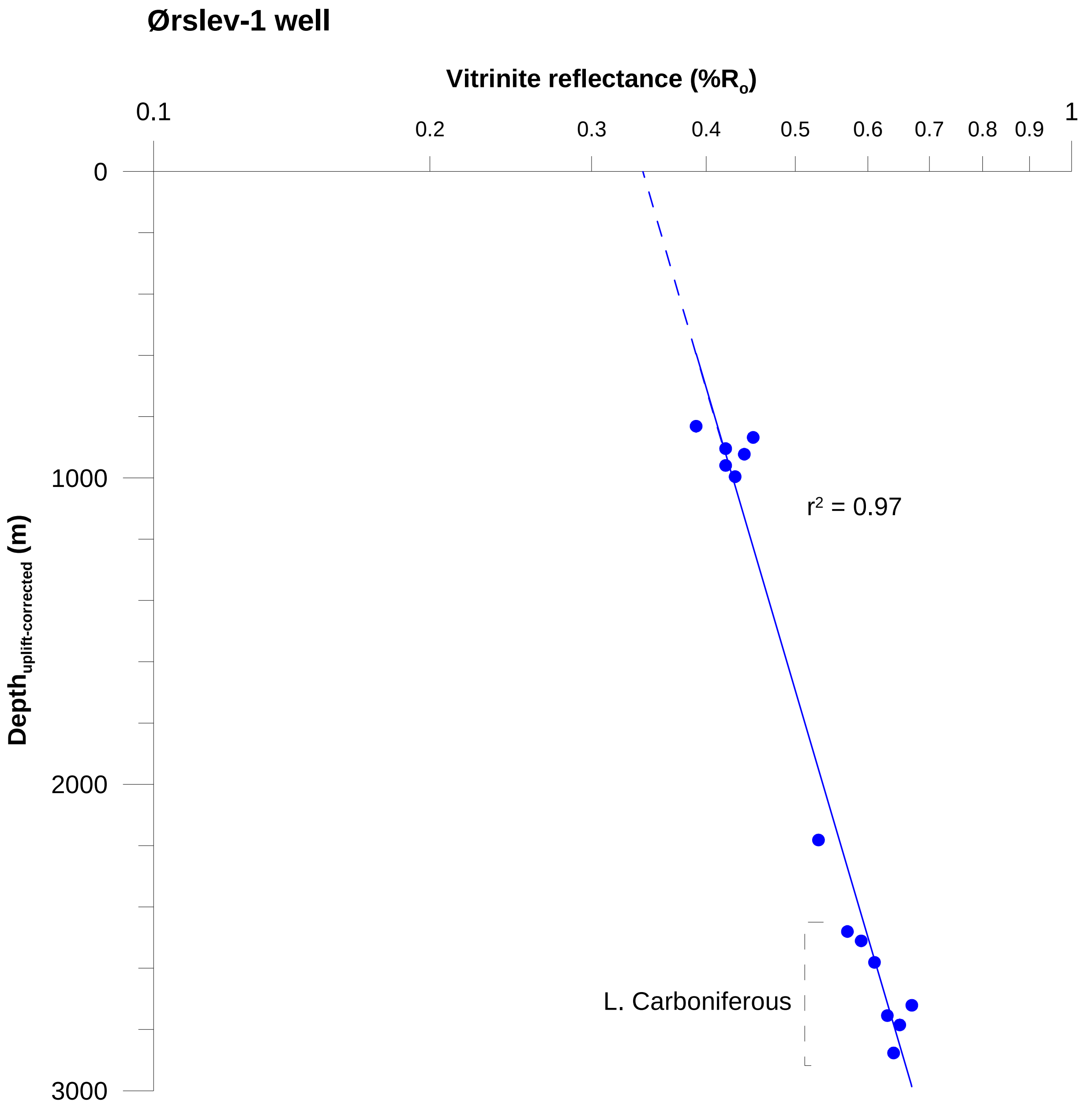
Ørslev-1 well
Vitrinite reflectance (%R_o)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1000
2000
3000
Depth$_{uplift-corrected}$ (m)
$r^2 = 0.97$
L. Carboniferous

Figure 6

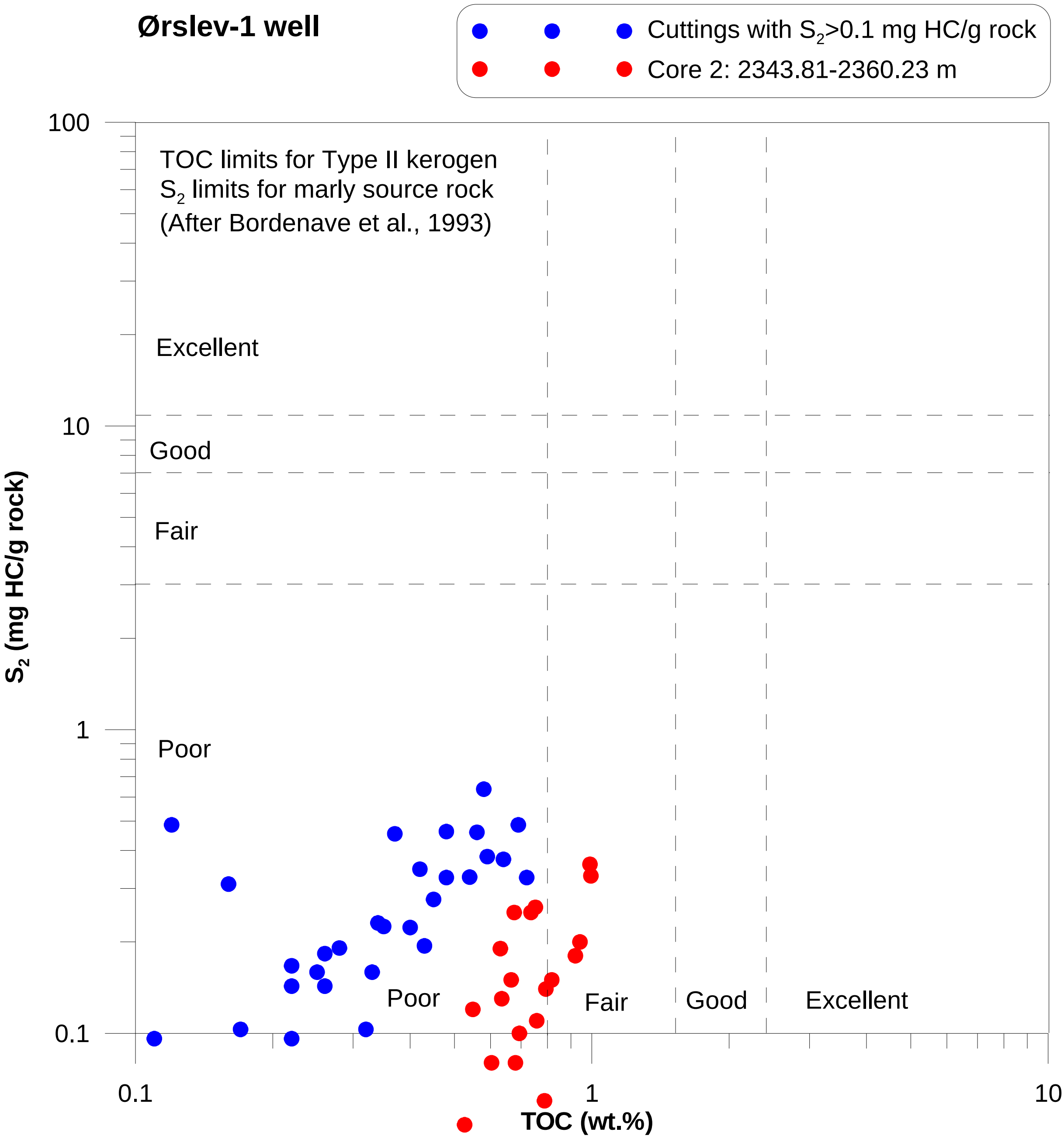
Ørslev-1 well
● ● ● Cuttings with S_2>0.1 mg HC/g rock
● ● ● Core 2: 2343.81-2360.23 m
TOC limits for Type II kerogen
S_2 limits for marly source rock
(After Bordenave et al., 1993)
Excellent
Good
Fair
Poor
Poor
Fair
Good
Excellent
100
10
1
0.1
0.1
1
10
S_2 (mg HC/g rock)
TOC (wt.%)

Figure 7

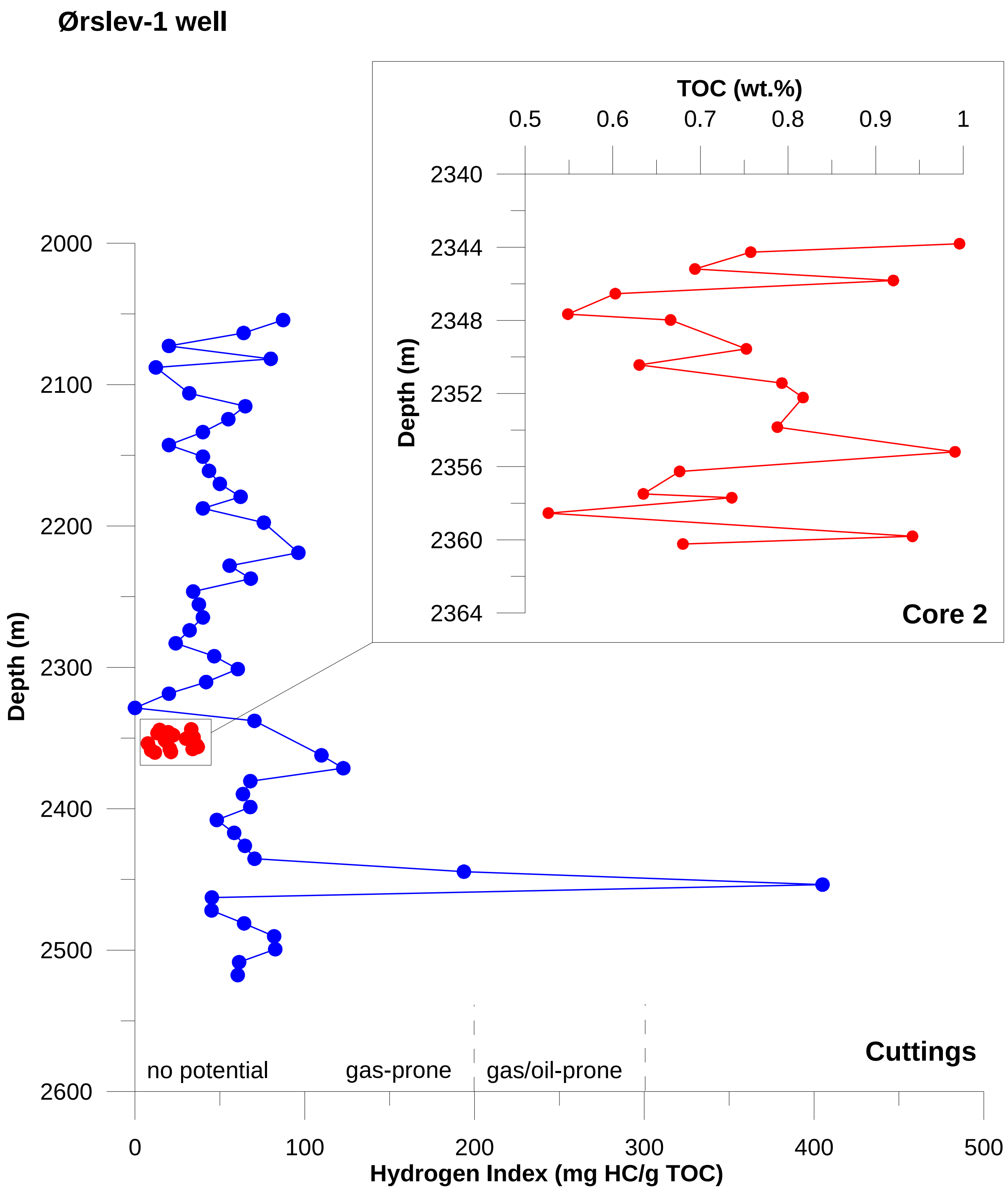
Ørslev-1 well
TOC (wt.%)
0.5
0.6
0.7
0.8
0.9
1
Depth (m)
2340
2344
2348
2352
2356
2360
2364
Core 2
2000
2100
2200
2300
2400
2500
2600
no potential
gas-prone
gas/oil-prone
Cuttings
0
100
200
300
400
500
Hydrogen Index (mg HC/g TOC)

Figure 8

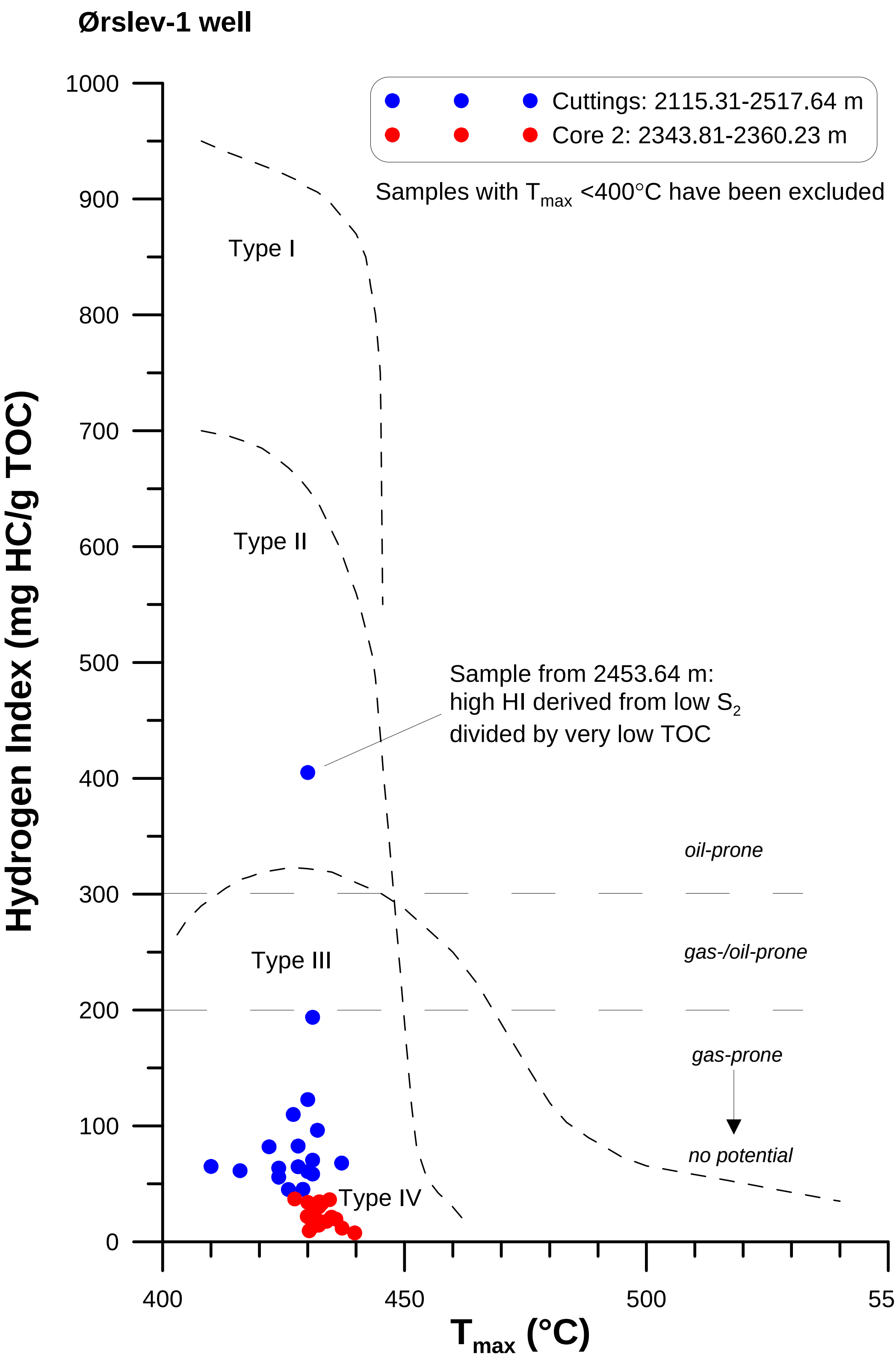
Ørslev-1 well
● ● ● Cuttings: 2115.31-2517.64 m
● ● ● Core 2: 2343.81-2360.23 m
Samples with T_{max} <400°C have been excluded
Hydrogen Index (mg HC/g TOC)
1000
900
800
700
600
500
400
300
200
100
0
Type I
Type II
Type III
Type IV
Sample from 2453.64 m:
high HI derived from low S_2
divided by very low TOC
oil-prone
gas-/oil-prone
gas-prone
no potential
400
450
500
550
T_{max} (°C)

Figure 9

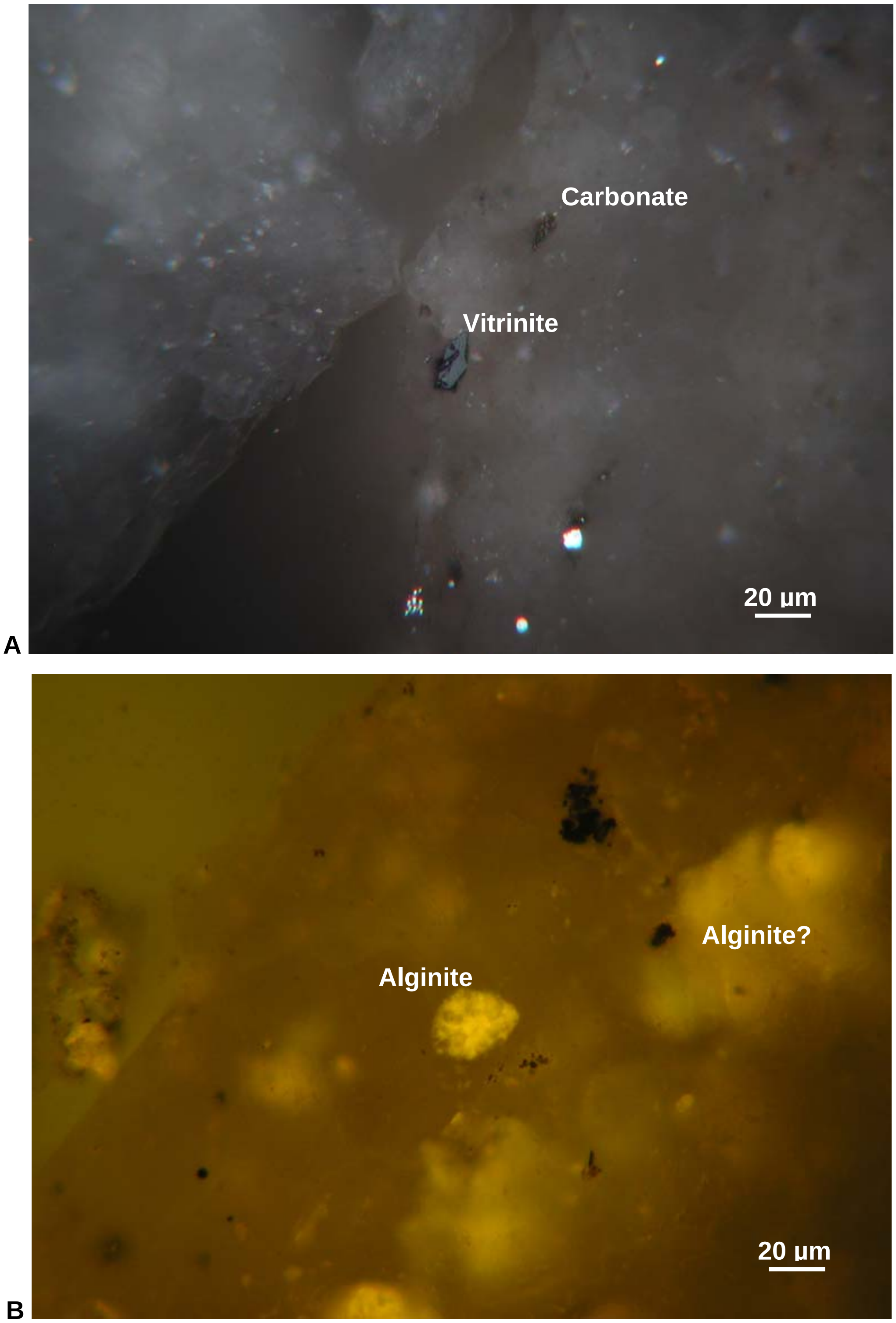

Figure 10

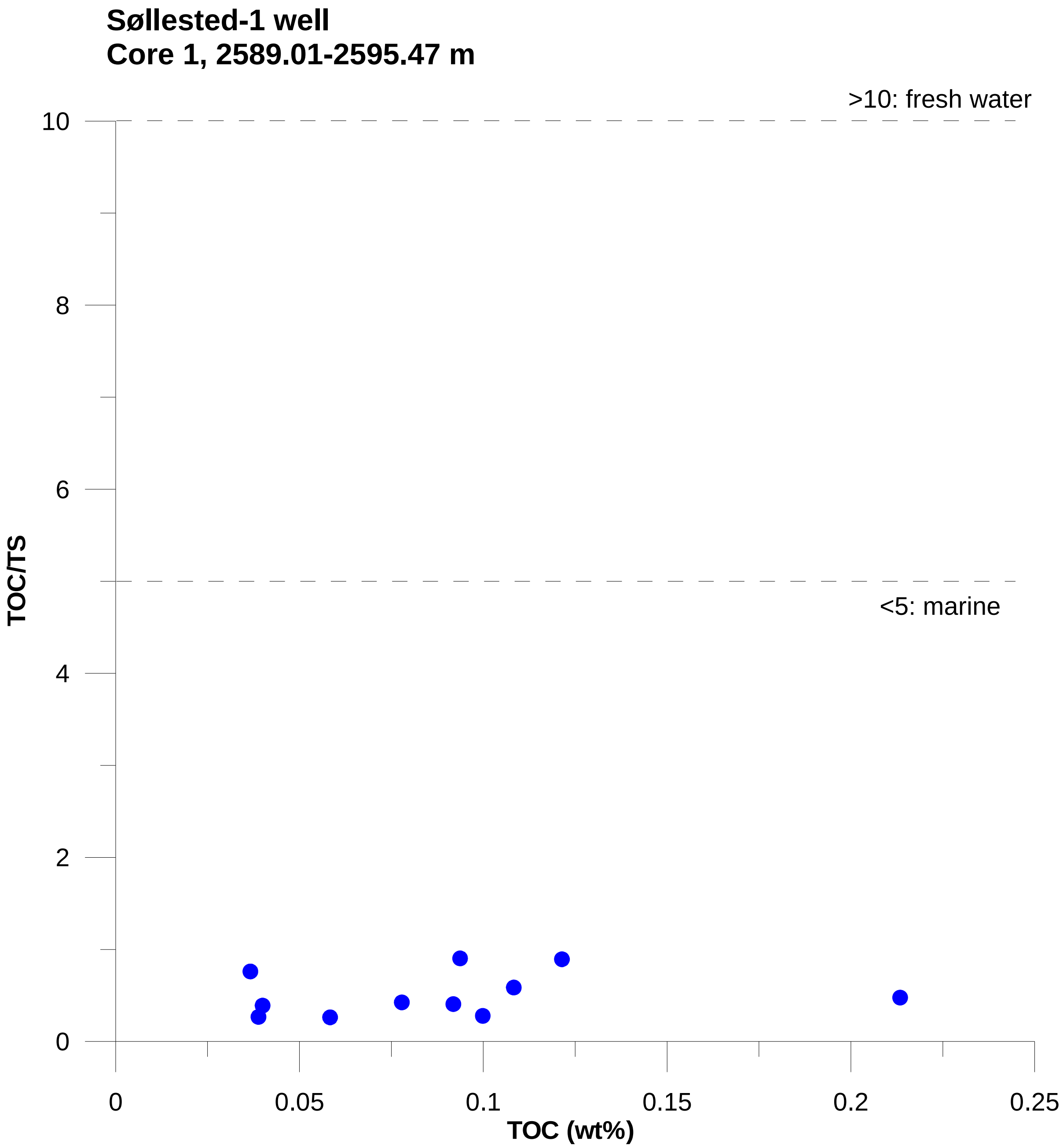
Søllested-1 well
Core 1, 2589.01-2595.47 m
>10: fresh water
<5: marine
TOC/TS
10
8
6
4
2
0
0
0.05
0.1
0.15
0.2
0.25
TOC (wt%)

Figure 11

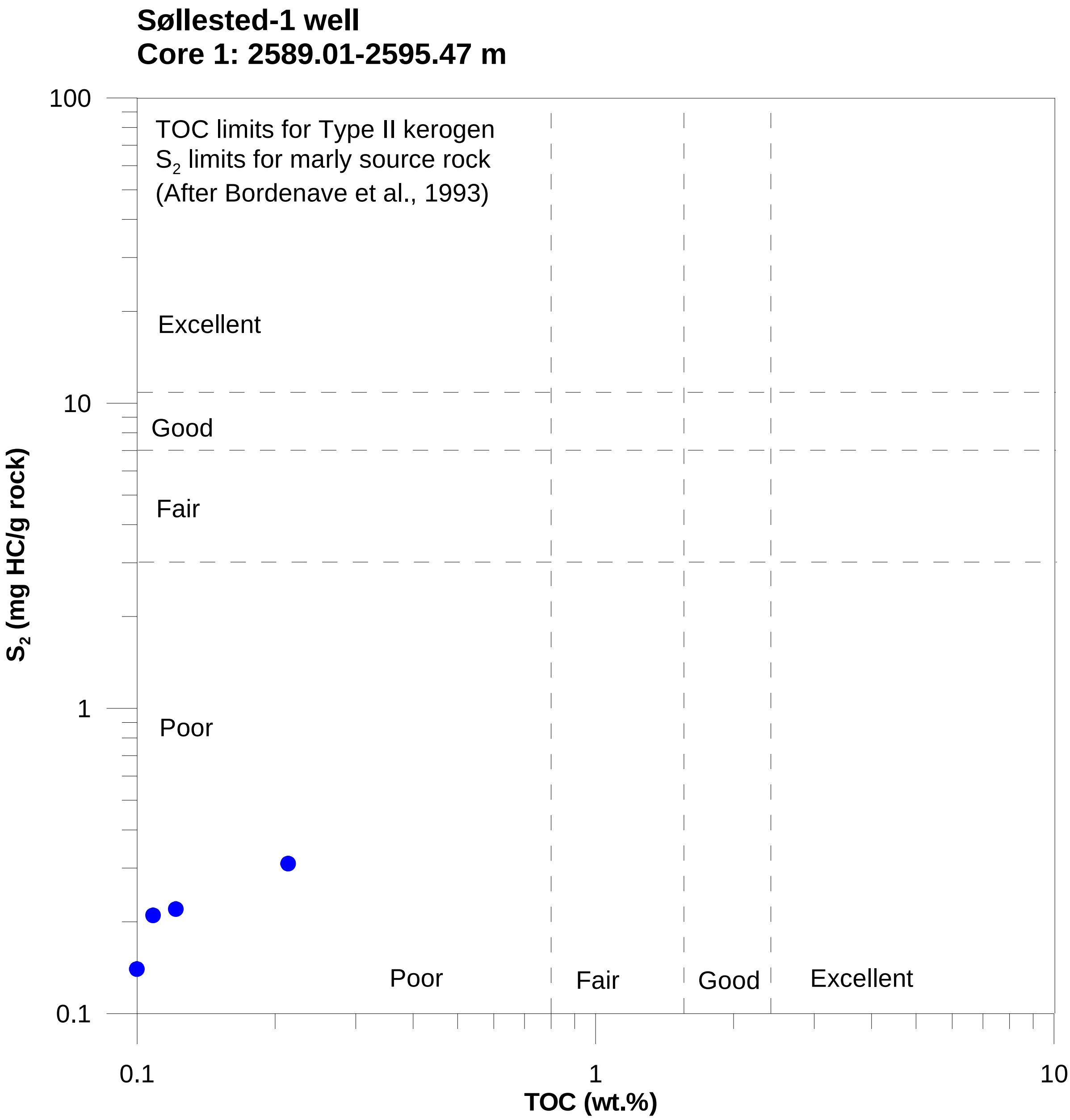
Søllested-1 well
Core 1: 2589.01-2595.47 m
TOC limits for Type II kerogen
S2 limits for marly source rock
(After Bordenave et al., 1993)
Excellent
Good
Fair
Poor
Poor
Fair
Good
Excellent
100
10
1
0.1
0.1
1
10
S2 (mg HC/g rock)
TOC (wt.%)

Figure 12

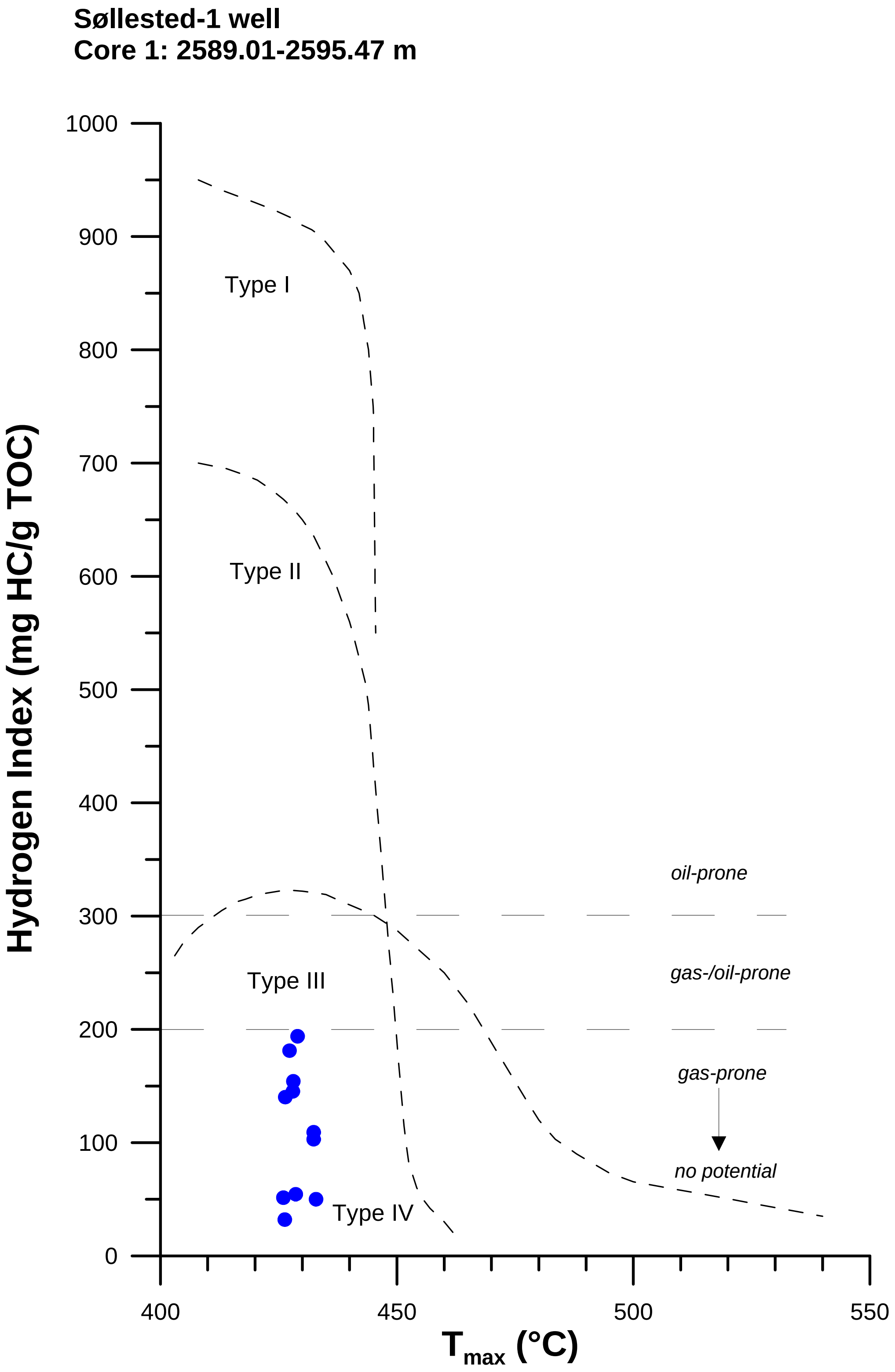
Søllested-1 well
Core 1: 2589.01-2595.47 m
Hydrogen Index (mg HC/g TOC)
1000
900
800
700
600
500
400
300
200
100
0
Type I
Type II
Type III
Type IV
oil-prone
gas-/oil-prone
gas-prone
no potential
400
450
500
550
T max (°C)

Figure 13

Table 1. Source rock data of the Lower Carboniferous section, Ørslev-1 well

Depth	Material	Epoch	TC	TOC	TC-TOC	T_{max}	S_1	S_2	HI	PI
m				wt.%		°C	mg HC/g rock			
2054,35	cuttings	L. Carboniferous	1,05	0,11	0,94		0,10	0,10	87	0,50
2063,49	cuttings	L. Carboniferous	2,35	0,05	2,30		0,06	0,03	64	0,64
2072,64	cuttings	L. Carboniferous	4,32	0,04	4,28		0,03	0,01	20	0,80
2081,78	cuttings	L. Carboniferous	6,68	0,07	6,61		0,08	0,06	80	0,59
2087,88	cuttings	L. Carboniferous	9,60	0,13	9,47		0,09	0,02	12	0,85
2106,16	cuttings	L. Carboniferous	9,53	0,10	9,43		0,09	0,03	32	0,73
2115,31	cuttings	L. Carboniferous	8,58	0,22	8,36	410	0,13	0,14	65	0,47
2124,45	cuttings	L. Carboniferous	8,59	0,26	8,33	361	0,16	0,14	55	0,53
2133,60	cuttings	L. Carboniferous	5,15	0,16	4,99		0,05	0,06	40	0,43
2142,74	cuttings	L. Carboniferous	1,60	0,08	1,52		0,04	0,02	20	0,71
2150,97	cuttings	L. Carboniferous	3,62	0,22	3,40		0,08	0,09	40	0,48
2161,03	cuttings	L. Carboniferous	7,30	0,22	7,08		0,11	0,10	44	0,54
2170,17	cuttings	L. Carboniferous	4,87	0,16	4,71		0,11	0,08	50	0,58
2179,32	cuttings	L. Carboniferous	1,10	0,09	1,01		0,09	0,06	62	0,61
2187,54	cuttings	L. Carboniferous	4,18	0,14	4,04		0,09	0,06	40	0,61
2197,60	cuttings	L. Carboniferous	4,72	0,22	4,50	272	0,16	0,17	76	0,49
2218,94	cuttings	L. Carboniferous	6,69	0,48	6,21	432	0,44	0,46	96	0,49
2228,08	cuttings	L. Carboniferous	6,41	0,40	6,01	424	0,20	0,22	56	0,47
2237,23	cuttings	L. Carboniferous	3,66	0,28	3,38	309	0,13	0,19	68	0,40
2246,37	cuttings	L. Carboniferous	3,32	0,14	3,18		0,04	0,05	34	0,45
2255,52	cuttings	L. Carboniferous	5,30	0,17	5,13		0,10	0,06	38	0,60
2264,66	cuttings	L. Carboniferous	7,89	0,22	7,67		0,09	0,09	40	0,50
2273,80	cuttings	L. Carboniferous	3,83	0,32	3,51	314	0,07	0,10	32	0,41
2282,95	cuttings	L. Carboniferous	2,49	0,10	2,39		0,04	0,02	24	0,63
2292,09	cuttings	L. Carboniferous	4,86	0,12	4,74		0,13	0,06	47	0,69
2301,24	cuttings	L. Carboniferous	7,16	0,17	6,99	342	0,19	0,10	61	0,65
2310,38	cuttings	L. Carboniferous	6,29	0,21	6,08		0,17	0,09	42	0,65
2318,61	cuttings	L. Carboniferous	8,68	0,16	8,52		0,07	0,03	20	0,69
2328,67	cuttings	L. Carboniferous	7,17	0,11	7,06		0,06	0,00	0	1,00
2337,81	cuttings	L. Carboniferous	4,51	0,26	4,25	270	0,18	0,18	70	0,49
2362,20	cuttings	L. Carboniferous	3,95	0,58	3,37	427	0,56	0,64	110	0,47
2371,34	cuttings	L. Carboniferous	5,98	0,37	5,61	430	0,70	0,45	123	0,61
2380,48	cuttings	L. Carboniferous	5,81	0,34	5,47	396	0,22	0,23	68	0,48
2389,63	cuttings	L. Carboniferous	6,80	0,25	6,55	424	0,16	0,16	64	0,50
2398,77	cuttings	L. Carboniferous	6,59	0,48	6,11	437	0,27	0,33	68	0,45
2407,92	cuttings	L. Carboniferous	4,65	0,33	4,32	344	0,13	0,16	48	0,44
2417,06	cuttings	L. Carboniferous	6,57	0,64	5,93	431	0,26	0,37	58	0,41
2426,20	cuttings	L. Carboniferous	6,68	0,59	6,09	428	0,24	0,38	65	0,38
2435,35	cuttings	L. Carboniferous	6,06	0,69	5,37	431	0,37	0,49	70	0,43
2444,49	cuttings	L. Carboniferous	7,59	0,16	7,43	431	0,25	0,31	194	0,44
2453,64	cuttings	L. Carboniferous	7,85	0,12	7,73	430	0,35	0,49	405	0,42
2462,78	cuttings	L. Carboniferous	8,91	0,72	8,19	429	0,28	0,33	45	0,46
2471,92	cuttings	L. Carboniferous	6,95	0,43	6,52	426	0,31	0,19	45	0,61
2481,07	cuttings	L. Carboniferous	3,73	0,35	3,38	388	0,19	0,23	64	0,46
2490,21	cuttings	L. Carboniferous	9,15	0,56	8,59	422	0,50	0,46	82	0,52
2499,36	cuttings	L. Carboniferous	9,10	0,42	8,68	428	0,26	0,35	83	0,42
2508,50	cuttings	L. Carboniferous	7,41	0,45	6,96	416	0,27	0,28	61	0,49
2517,64	cuttings	L. Carboniferous	8,22	0,54	7,68	430	0,30	0,33	61	0,48

▨ Unreliable low values

Table 2. Source rock data of Lower Carboniferous core samples, core 2, Ørslev-1 well

Lab. no.	**Depth**	**Material**	**TC**	**TOC**	**TC-TOC**	**TS**	**TOC/TS**	**T_{max}**	**S_1**	**S_2**	**HI**	**PI**
	m		**wt.%**					**°C**	**mg HC/g rock**			
23321	2343,81	core	3,31	1,00	2,32	2,20	0,45	433	0,03	0,33	33	0,08
23322	2344,27	core	3,99	0,76	3,23	1,68	0,45	432	0,02	0,11	15	0,15
23323	2345,19	core	3,14	0,69	2,45	1,49	0,47	432	0,01	0,10	14	0,09
23324	2345,82	core	2,12	0,92	1,20	1,96	0,47	436	0,03	0,18	20	0,14
23325	2346,54	core	4,48	0,60	3,88	2,43	0,25	431	0,00	0,08	13	0
23326	2347,66	core	6,66	0,55	6,11	1,48	0,37	430	0,01	0,12	22	0,08
23327	2347,98	core	5,28	0,67	4,61	1,95	0,34	431	0,02	0,15	23	0,12
23328	2349,56	core	4,60	0,75	3,85	1,82	0,41	432	0,02	0,26	35	0,07
23329	2350,44	core	6,04	0,63	5,41	1,12	0,56	432	0,02	0,19	30	0,10
23330	2351,43	core	2,21	0,79	1,42	1,87	0,42	434	0,02	0,14	18	0,13
23331	2352,22	core	1,46	0,82	0,64	1,74	0,47	432	0,02	0,15	18	0,12
23332	2353,84	core	0,83	0,79	0,04	0,45	1,76	440	0,02	0,06	8	0,25
23333	2355,19	core	2,41	0,99	1,42	3,53	0,28	435	0,04	0,36	36	0,10
23334	2356,26	core	4,18	0,68	3,50	2,22	0,31	427	0,01	0,25	37	0,04
23335	2357,49	core	4,58	0,63	3,94	1,98	0,32	430	0,02	0,13	20	0,13
23336	2357,70	core	3,72	0,74	2,99	1,66	0,44	430	0,04	0,25	34	0,14
23337	2358,54	core	2,72	0,53	2,19	1,61	0,33	430	0,01	0,05	9	0,17
23338	2359,81	core	2,83	0,94	1,88	1,97	0,48	435	0,03	0,20	21	0,13
23339	2360,23	core	1,45	0,68	0,77	0,73	0,94	437	0,01	0,08	12	0,11

Table 3. Source rock data of Zechstein (Z2) core samples, core 1, Søllested-1 well

Lab. no.	Depth	Material	TOC	TC	TC-TOC	TS	TOC/TS	T_{max}	S_1	S_2	HI	PI
	m		wt.%					°C	mg HC/g rock			
23310	2589,01	core	0,09	11,73	11,64	0,10	0,90	426	0,03	0,03	32	0,50
23311	2592,94	core	0,10	11,17	11,07	0,36	0,28	426	0,09	0,14	140	0,39
23312	2593,30	core	0,09	10,80	10,71	0,23	0,41	429	0,05	0,05	54	0,50
23313	2593,52	core	0,06	11,46	11,40	0,22	0,26	426	0,04	0,03	51	0,57
23314	2593,80	core	0,21	11,35	11,14	0,45	0,48	428	0,11	0,31	145	0,26
23315	2594,50	core	0,12	11,71	11,59	0,14	0,89	427	0,11	0,22	181	0,33
23316	2594,84	core	0,04	11,76	11,72	0,05	0,76	432	0,02	0,04	109	0,33
23317	2595,06	core	0,04	10,87	10,83	0,10	0,39	433	0,02	0,02	50	0,50
23318	2595,14	core	0,04	11,38	11,34	0,15	0,27	432	0	0,04	103	0
23319	2595,35	core	0,11	11,43	11,32	0,18	0,59	429	0,06	0,21	194	0,22
23320	2595,47	core	0,08	11,02	10,94	0,18	0,42	428	0,07	0,12	154	0,37

Table 4. Vitrinite reflectance (random) values

Lab. no.	Epoch	Material	$\text{Depth}_{\text{present day}}$ m	$\text{Depth}_{\text{chalk corr}}$*. m	VR %R_o	Std.	N
94A	L. Jurassic	cuttings	469,39	831,39	0,39	0,05	32
95A	L. Jurassic	cuttings	505,97	867,97	0,45	0,05	33
96A	L. Jurassic	cuttings	542,54	904,54	0,42	0,05	104
97A	L. Jurassic	cuttings	560,83	922,83	0,44	0,06	66
98A	U. Triassic	cuttings	597,41	959,41	0,42	0,06	106
99A	U. Triassic	cuttings	633,98	995,98	0,43	0,04	104
112A	U. Permian	cuttings	1819,66	2181,66	0,53	0,03	6
116A	L. Carboniferous	cuttings	2118,36	2480,36	0,57	0,04	12
117A	L. Carboniferous	cuttings	2148,84	2510,84	0,59	0,04	31
119A	L. Carboniferous	cuttings	2218,94	2580,94	0,61	0,06	21
133AW	L. Carboniferous	core	2359,02	2721,02	0,67	0,07	50
125A	L. Carboniferous	cuttings	2392,68	2754,68	0,63	0,09	29
126A	L. Carboniferous	cuttings	2423,16	2785,16	0,65	0,07	45
129A	L. Carboniferous	cuttings	2514,60	2876,60	0,64	0,05	12

*Present day depth corrected for net exhumation of 362 m based on chalk sonic velocities (Japsen and Bidstrup, 1999)