

**Source rock investigation of part of
the Rotliegende succession of
the Felicia-1A well**

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and Hans P. Nytoft

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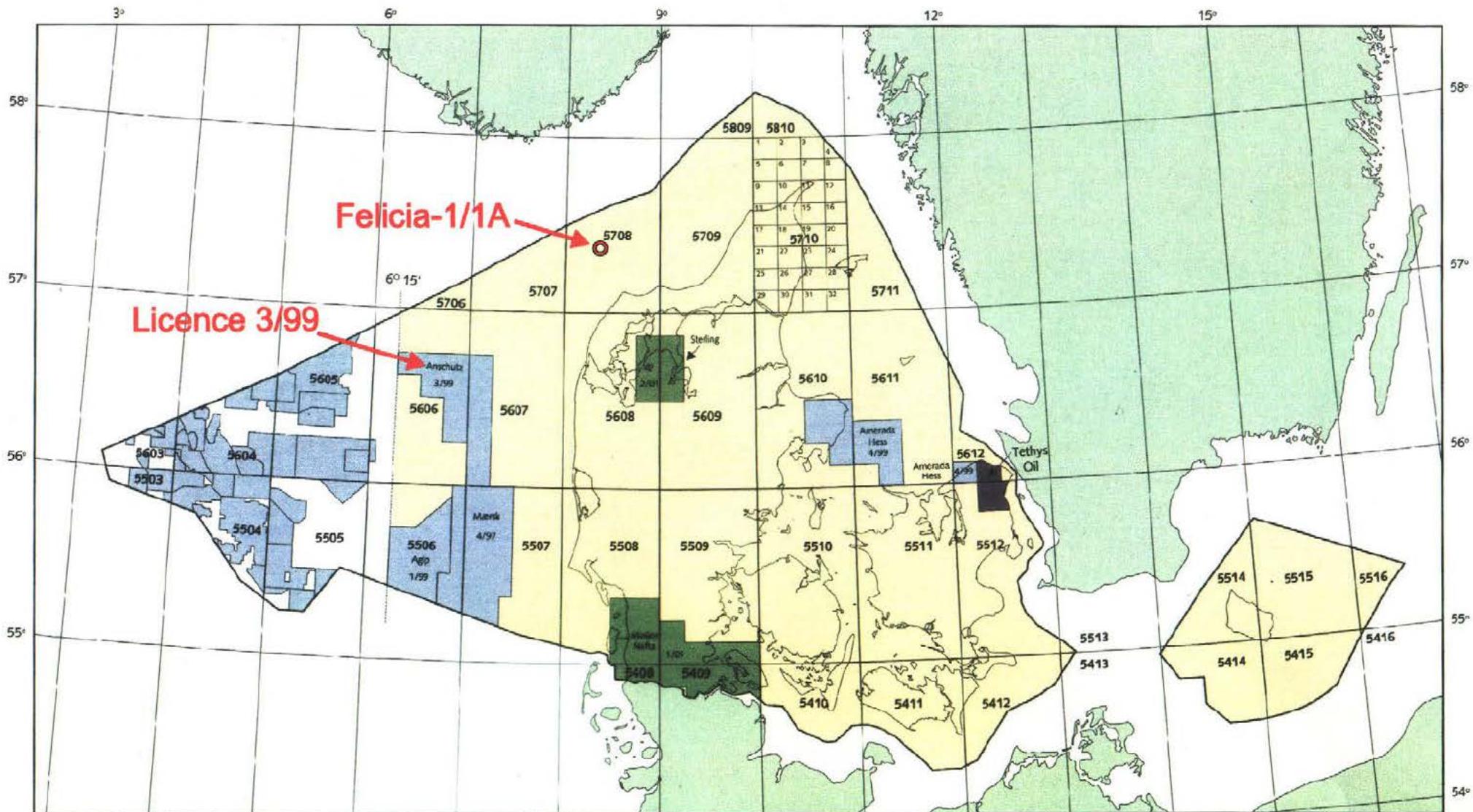


Fig. 1. Location map

Introduction

This report presents organic geochemical data on part of the Permian succession (5092 – 5260 m) penetrated by the Felicia-1A well in the Skagerrak, Denmark (Fig. 1).

Anschutz Denmark ApS holds the 3/99 licence in the North Sea (Fig. 1) and in conjunction with its exploration activities, the company conducted an organic geochemical study of the Rotliegende succession of the Felicia-1A well, which is, however, situated northeast of the licence area.

The outcome of the study was rather surprising, indicating the presence of rich, oil-prone source rocks in the Permian succession, that is otherwise known to be dominated by evaporites and continental redbeds.

Due to the controversial nature of the results, GEUS carried out a similar study, using samples collected at the very same depths as the samples included in the Anschutz study, in order to verify or falsify the results of the latter.

The results of the GEUS study plus comparison to the results of the Anschutz study and data obtained from geochemical analyses conducted by Statoil are reported herein.

Samples and methods

The Anschutz study comprised 44 ditch cutting samples (Table 1), covering the interval 5104 – 5257 m b. rfl. It is not known whether these samples were prewashed (washed and dried cuttings) or wet bagged cutting samples that were cleaned by the Marathon Oil geochemical laboratory, that carried out the analyses on behalf of Anschutz. It is suspected that the analyses were carried out on prewashed samples. The samples were subjected to standard Rock-Eval screening pyrolysis, using Rock-Eval 6 instrumentation.

The GEUS study comprised 50 wet bagged ditch cutting samples, covering the interval 5092 – 5260 m b. rfl. The samples were cleaned by GEUS, and showed pervasive contamination with oil or grease-like compounds, giving off a strong "wet paint like" odour. The samples were strongly water-repellent, and cuttings could only be retrieved from the samples by allowing the mud+cutting mixture to soak in detergent-containing (standard dish washing detergent) warm water for extended periods of time with intermittent rinsing under warm water on a brass sieve.

All samples were subjected to Total Carbon (TC), Total Sulphur (TS), and Total Organic Carbon (TOC) analysis, using a Leco CS-200 induction furnace, and standard Rock-Eval screening pyrolysis, using Rock-Eval 6 instrumentation (Bordenave et al., 1993) (Tables 2 and 3).

Based on screening data 5 samples (Lab. no. 8703, 8723, 8730, 8737 and 8744; Tables 2 and 3) were selected for organic petrographic examination by means of reflected light microscopy equipped with both white light and fluorescence-inducing blue light (Taylor et al., 1998).

Six core samples (Lab. no. 8991, 8992, 8993, 8994, 8995 and 8996; Table 4) were subjected to TC/TS/TOC analysis (Leco CS-200), standard Rock-Eval screening pyrolysis (Rock-Eval 6), and evaluation of the organic content by reflected light microscopy. The samples were collected from thin black, shaly intervals after careful examination of the cores in an attempt to retrieve data from the presumably most favourable levels.

Three mud+cutting samples were extracted by dichloromethane, and the saturated hydrocarbon fraction of the extracts were subjected to GC-MS analysis by means of a Hewlett Packard 5890 series II gas chromatograph coupled to a Hewlett Packard 5971A quadropole mass spectrometer in an attempt to identify the contaminant.

In addition, standard screening data from 30 ditch cutting samples analysed by Statoil were included (Geochem Laboratories, 1988) (Table 6).

Table 1: Anschutz screening data (cutting samples)

Depth (m)	TOC (wt. %)	Tmax (°C)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	HI	OI	PI
5107	1,29	436	1,27	7,73	1,25	599	97	0,14
5110	0,95	438	0,75	3,34	0,99	352	104	0,18
5113	0,94	438	0,72	2,97	0,86	316	91	0,20
5116	1,51	443	0,77	2,86	0,79	189	52	0,21
5119	1,13	391	0,59	3,96	4,04	350	358	0,13
5122	0,80	428	0,32	1,61	0,75	201	94	0,17
5125	1,07	443	0,45	2,41	0,77	225	72	0,16
5128	0,61	433	0,29	1,56	0,85	256	139	0,16
5131	0,50	422	0,22	0,92	0,66	184	132	0,19
5134	0,74	434	0,40	1,58	0,79	214	107	0,20
5137	0,84	393	0,20	1,41	0,80	168	95	0,12
5140	0,87	443	0,21	1,51	0,39	174	45	0,12
5143	1,07	398	0,32	2,04	0,60	191	56	0,14
5146	0,88	452	0,25	1,15	0,26	131	30	0,18
5149	0,50	447	0,16	0,86	0,27	172	54	0,16
5152	0,48	445	0,21	1,22	0,30	254	63	0,15
5155	0,30	443	0,18	0,94	0,27	313	90	0,16
5158	0,27	444	0,14	0,70	0,21	259	78	0,17
5164	1,56	450	0,79	2,44	0,54	156	35	0,25
5167	0,61	445	0,31	2,18	0,75	357	123	0,12
5176	3,69	446	1,15	15,94	4,27	432	116	0,07
5185	1,46	451	0,83	7,90	1,59	541	109	0,10
5191	1,76	447	1,64	12,34	1,80	701	102	0,12
5194	1,69	443	1,84	11,37	1,52	673	90	0,14
5197	1,58	442	1,50	9,74	1,77	616	112	0,13
5200	1,64	444	1,16	9,76	1,65	595	101	0,11
5203	1,55	451	1,69	11,7	1,71	755	110	0,13
5209	2,12	440	1,79	10,23	1,49	483	70	0,15
5212	1,98	442	1,52	8,74	1,52	441	77	0,15
5215	1,57	439	1,07	8,13	1,63	518	104	0,12
5218	1,16	444	1,57	7,25	1,39	625	120	0,18
5221	1,43	439	1,14	6,59	1,59	461	111	0,15
5224	1,43	442	1,31	8,30	1,48	580	103	0,14
5227	1,23	442	0,99	6,24	1,21	507	98	0,14
5230	1,34	440	0,75	4,65	1,43	347	107	0,14
5233	1,22	441	1,18	6,36	1,35	521	111	0,16
5236	1,35	439	1,01	5,90	1,27	437	94	0,15
5239	1,21	439	0,73	4,54	1,41	375	117	0,14
5242	1,81	445	1,09	5,88	1,30	325	72	0,16
5245	1,44	443	0,96	5,97	1,57	415	109	0,14
5248	1,28	448	0,76	5,16	1,12	403	88	0,13
5251	1,13	443	0,73	4,17	1,08	369	96	0,15
5254	1,39	444	0,67	3,55	1,17	255	84	0,16
5257	0,80	397	0,55	2,64	1,56	330	195	0,17

Table 2: GEUS screening data (cutting samples)

Lab. no.	Depth (m)	TOC (wt. %)	Tmax (°C)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	HI	OI	PI
8700	5095	1,54	435	18,35	5,89	0,58	383	38	0,76
8701	5101	1,18	425	11,29	4,34	0,66	369	56	0,72
8702	5104	0,72	441	7,52	2,93	0,87	407	121	0,72
8703	5107	1,20	427	15,46	3,86	0,92	322	77	0,80
8704	5110	1,08	434	15,70	3,98	0,85	370	79	0,80
8705	5113	1,18	428	8,29	2,58	0,44	218	37	0,76
8706	5116	1,28	427	10,16	2,83	0,30	221	23	0,78
8707	5119	1,42	443	6,02	9,68	2,78	684	196	0,38
8708	5122	1,03	426	3,38	3,53	0,49	342	47	0,49
8709	5125	0,59	428	3,06	1,47	0,19	250	32	0,68
8710	5128	0,46	428	2,46	1,68	0,25	362	54	0,59
8711	5131	0,66	429	1,23	1,16	0,29	175	44	0,51
8712	5134	0,64	435	2,07	1,36	0,20	213	31	0,60
8713	5137	0,69	435	2,27	1,18	0,26	170	37	0,66
8714	5140	0,67	435	1,23	1,07	0,31	159	46	0,53
8715	5143	0,85	438	1,60	1,30	0,24	153	28	0,55
8716	5146	0,60	438	1,16	0,90	0,13	151	22	0,56
8717	5149	0,44	438	1,01	0,69	0,42	156	95	0,59
8718	5152	0,39	437	0,88	0,88	0,25	228	65	0,50
8719	5155	0,25	430	0,70	0,71	0,33	283	131	0,50
8720	5158	0,25	435	0,51	0,46	0,28	186	113	0,53
8721	5164	0,38	422	0,57	0,47	0,25	124	66	0,55
8722	5167	0,43	435	0,96	1,02	0,40	236	93	0,48
8723	5176	3,18	445	10,35	21,56	6,26	679	197	0,32
8724	5185	1,44	445	49,10	15,55	2,75	1077	191	0,76
8725	5188	1,25	446	52,79	18,07	3,30	1441	263	0,74
8726	5191	1,03	449	68,64	20,22	2,93	1967	285	0,77
8727	5194	1,77	449	19,52	11,64	2,47	656	139	0,63
8728	5197	1,34	449	4,06	9,03	2,40	676	180	0,31
8729	5200	1,40	446	16,90	11,02	2,65	786	189	0,61
8730	5203	1,49	447	46,71	14,53	3,07	973	206	0,76
8731	5209	1,40	448	8,67	5,58	1,59	397	113	0,61
8732	5212	0,97	442	2,92	2,87	1,08	297	112	0,50
8733	5215	1,03	443	5,69	4,41	1,44	430	140	0,56
8734	5218	0,75	445	2,78	4,43	1,10	593	147	0,39
8735	5221	0,76	436	1,80	2,43	0,72	318	94	0,43
8736	5224	0,79	445	1,39	2,19	0,63	277	80	0,39
8737	5227	0,93	447	4,96	5,31	1,17	570	126	0,48
8738	5230	1,00	427	1,22	2,18	0,53	217	53	0,36
8739	5233	0,91	421	1,26	2,18	0,55	240	60	0,37
8740	5236	1,29	429	2,23	2,23	0,46	173	36	0,50
8741	5239	0,81	434	1,33	2,39	0,59	296	73	0,36
8742	5242	1,33	436	2,06	2,54	0,61	191	46	0,45
8743	5245	1,15	434	2,01	3,27	0,96	285	84	0,38
8744	5248	1,07	444	4,07	3,48	1,02	325	95	0,54
8745	5251	0,86	443	2,34	2,37	0,71	275	82	0,50
8746	5254	0,93	435	1,50	1,89	0,59	202	63	0,44
8747	5257	1,38	445	2,73	3,40	0,99	247	72	0,45
8748	5260	1,11	428	3,75	4,86	1,26	439	114	0,44
8749	5263	0,29	421	1,11	1,38	0,58	479	202	0,45

Table 3: GEUS screening data (cutting samples)

Lab. no.	Depth (m)	TC (wt. %)	TS (wt.%)
8700	5095	3,69	8,16
8701	5101	2,27	1,33
8702	5104	2,38	1,36
8703	5107	2,68	1,62
8704	5110	2,35	1,43
8705	5113	1,85	1,53
8706	5116	2,17	2,03
8707	5119	3,34	1,38
8708	5122	3,31	1,60
8709	5125	2,74	1,03
8710	5128	2,10	1,03
8711	5131	5,08	1,48
8712	5134	4,10	1,43
8713	5137	4,03	1,46
8714	5140	5,87	2,09
8715	5143	5,29	2,58
8716	5146	8,87	1,37
8717	5149	9,54	2,23
8718	5152	9,61	3,34
8719	5155	9,52	3,84
8720	5158	9,30	4,36
8721	5164	3,72	2,68
8722	5167	6,00	2,56
8723	5176	6,84	5,26
8724	5185	5,72	1,55
8725	5188	6,46	1,63
8726	5191	8,04	1,59
8727	5194	3,80	1,31
8728	5197	3,72	1,37
8729	5200	4,29	1,43
8730	5203	6,01	1,34
8731	5209	3,24	1,11
8732	5212	2,70	0,72
8733	5215	3,07	1,00
8734	5218	3,11	0,80
8735	5221	2,17	0,79
8736	5224	2,28	0,71
8737	5227	2,91	0,93
8738	5230	2,24	1,17
8739	5233	1,94	0,95
8740	5236	1,91	1,40
8741	5239	1,89	1,08
8742	5242	2,43	1,52
8743	5245	2,53	0,96
8744	5248	3,34	0,97
8745	5251	3,11	0,90
8746	5254	3,30	1,17
8747	5257	3,39	0,85
8748	5260	2,49	1,02
8749	5263	1,08	0,21

Table 4: GEUS screening data (core samples)

Lab. no.	Depth (m)	TOC (wt. %)	Tmax (°C)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	HI	OI	PI
8991	5176,25	0,37	490	0,01	0,06	0,20	16	55	0,14
8992	5177,05	0,54	490	0,01	0,13	0,15	24	28	0,07
8993	5178,65	1,25	487	0,05	0,38	0,04	30	3	0,12
8994	5180,38	0,46	494	0,01	0,10	0,01	22	2	0,09
8995	5183,51	1,58	480	0,04	0,44	n.a.	28	2	0,08
8996	5183,83	1,73	485	0,08	0,56	0,12	32	7	0,13

Table 5: GEUS screening data (core samples)

Lab. no.	Depth (m)	TC (wt. %)	TS (wt.%)
8991	5176,25	3,92	0,13
8992	5177,05	3,23	0,52
8993	5178,65	1,36	1,94
8994	5180,38	1,18	0,47
8995	5183,51	1,55	3,28
8996	5183,83	1,92	0,47

Table 6: Statoil screening data (cutting samples)

Depth (m)	TOC (wt. %)	Tmax (°C)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	HI	OI	PI
5116	0,89	407	1,53	0,51	0,54	57	61	0,75
5125	0,86	406	0,67	0,42	0,67	49	78	0,62
5134	0,14	423	0,05	0,15	0,25	107	179	0,25
5134	1,38	440	0,49	0,76	0,57	55	41	0,40
5143	0,32	431	0,12	0,24	0,27	75	84	0,33
5143	0,77	445	0,21	0,59	0,64	77	83	0,26
5152	0,35	418	0,19	0,25	0,35	71	100	0,43
5152	0,64	447	0,30	0,36	0,23	56	36	0,45
5161	0,24	427	0,10	0,19	0,27	79	113	0,36
5170	0,19	398	0,06	0,12	0,24	63	126	0,33
5170	1,15	452	0,29	0,54	0,37	47	32	0,35
5179	1,42	413	0,32	0,78	1,15	55	81	0,29
5188	1,7	394	0,42	2,05	1,52	121	89	0,17
5197	1,02	446	1,73	2,56	1,41	251	138	0,40
5197	1,35	438	0,29	0,78	0,97	58	72	0,27
5206	0,48	445	1,30	3,15	1,30	656	271	0,29
5206	1,11	430	0,40	0,59	0,79	53	71	0,41
5215	0,28	441	0,14	0,87	0,50	311	179	0,14
5215	0,76	445	0,22	0,53	0,69	70	91	0,30
5224	0,12	380	0,10	0,16	0,63	133	525	0,38
5224	0,56	415	0,17	0,36	0,66	64	118	0,33
5233	0,18	437	0,06	0,22	0,39	122	217	0,21
5233	0,92	430	0,21	0,45	0,67	49	73	0,32
5242	0,31	429	0,14	0,55	0,57	177	184	0,21
5242	1,07	445	0,31	0,70	1,04	65	97	0,31
5251	0,33	447	0,25	1,35	0,52	409	158	0,16
5251	0,98	412	0,26	0,48	0,70	49	71	0,35
5260	2,3	402	0,22	0,47	1,24	20	54	0,32
5260	0,38	440	0,39	0,98	1,27	258	334	0,29

Results: description and comparison of data

Screening data from cutting and core samples

The results of the TOC, TC and TS analyses performed by GEUS on the cutting samples are listed in Tables 2, 3 and 6, and in Figure 2 they are plotted with depth. The difference between the TOC and TC content for the same depth shows that the cutting samples contain significant proportions of inorganic bound carbon, probably in carbonate. From 5095 m to 5167 m the TOC content displays a decreasing trend from 1.54 wt.% to <0.5 wt.%. A peak in TOC of 3.18 wt.% is observed at 5176 m, followed by a TOC content generally fluctuating between 0.75 wt.% and 1.5 wt.%. Apart from a very high TS content at 5092 m, TS shows an overall increasing trend up to a maximum of 5.26 wt.% at 5173 m, which is followed by a minor interval with TS contents from 1.03–1.77 wt.%. Below 5218 m the TS content is generally close to or less than 1 wt.%. Much of the TS content can be related to a high pyrite content as evidenced by microscopy (see below).

The TOC content of the six core samples analysed by GEUS vary from 0.37 wt.% to 1.73 wt.%, and comparison to the TC content reveal that some of the core samples contain a considerably amount of inorganic carbon (Tables 4 and 5). The TS content range from 0.13 wt.% to 3.28 wt.%, and again visual inspection of the samples indicate that the high TS contents are related to high amounts of pyrite (see below).

The TOC data from GEUS are compared with the data from Anschutz and Statoil in Figure 3. All three data-sets show more or less the same overall trend in the TOC content throughout the investigated interval. In particular the TOC data from GEUS and Anschutz exhibit very similar trends, whereas the Statoil data appear to be more fluctuating. This may in part be caused by the lower number of samples analysed by Statoil thereby preventing recognition of more subtle trends in TOC. The data from GEUS and Anschutz show a high degree of agreement in the depth interval 5095–5176 m, whereas the GEUS TOC data are slightly lower below this interval (Fig. 4). Also shown in Figure 3 are the results of the 6 core samples analysed by GEUS. The uppermost 4 core samples yield much lower TOC contents than the high values derived from analysis of cutting samples from the same depth interval.

Hydrogen Index values obtained from analysis of cutting samples by GEUS, Anschutz and Statoil are listed in Tables 1, 2 and 6, and the values are compared in Figure 5. The three data-sets show an overall similar trend in HI with increasing depth, and particularly trends of the HI data from GEUS and Anschutz are comparable. In the interval 5095–5167 m the data are nearly identical, but below this depth the GEUS data show an increase in HI to exceptional high HI values with a maximum of HI=1967. The Anschutz data likewise display an increase, albeit not as pronounced as the GEUS data, to a maximum HI of 755. The Statoil data yield a maximum HI value of 656. The 6 core samples analysed by GEUS are also plotted on Figure 5, and these samples yield conspicuously lower HI values with a maximum HI of only 32 (Table 4). It is particularly notable that these very low HI values from the cores are obtained from the same stratigraphic interval where the cutting samples yield extraordinarily high HI values.

The Production Index (PI) values obtained by Anschutz are lower than the PI results of GEUS (Tables 1 and 2). A possible explanation could be that Anschutz may have been analysed on washed and dried cuttings on the rig and the cutting samples were therefore not contaminated to the same extent as the GEUS samples, which have been left wet for several years.

The T_{max} values obtained from the three studies are listed in Tables 1, 2 and 6, the data are compared in the plot in Figure 6. Down to 5167 m the GEUS data show T_{max} values between 425°C and 440°C while in the deeper part the a majority of the values range from 442–449°C. The GEUS and Anschutz data are quite similar, although the Anschutz data display some very low T_{max} values in the upper part of the investigated section. T_{max} values obtained from the Statoil study are inconsistent with a very large scatter in the data-set. The 6 core samples analysed by GEUS yield significantly higher T_{max} values, namely 480–494 m.

Petrographic examination of cutting and core samples

A total of 11 samples have been subjected to examination by binocular and reflected light microscopy, 5 cutting samples and 6 core samples. Figures 7 and 8 are photomicrographs taken in reflected white light and oil immersion.

Cutting samples

Visual inspection by binocular microscopy shows the presence of rubbery material, which particles show clear resemblance to black shale.

The cutting samples are composed of similar types of cuttings, and few of the cuttings contain some organic material of varying particle size. Reflected light microscopy reveals that the organic material is primarily composed of vitrinite and inertinite (Fig. 7). No fluorescing organic material has been observed. Pyrite occurs in larger amounts, commonly in the same cuttings that contain the organic matter (Fig. 7).

Core samples

Lab. no. 8991; 5176.25 m: Homogeneous sediment associated with organic matter of varying particle size. The organic matter is composed of vitrinite and inertinite. No fluorescing organic material has been observed. Pyrite occurs in minor proportions.

Lab. no. 8992; 5177.05 m: Same sediment type as in sample 8991, although darker areas associated with large amounts of pyrite occur (Fig. 8a). These dark sediment areas also contain organic matter in the form of vitrinite and inertinite. No fluorescing organic material has been observed.

Lab. no. 8993; 5178.65 m: Homogeneous sediment containing large amounts of vitrinite and inertinite of varying particle size, and large amounts of pyrite (Fig. 8b,c). No fluorescing organic material has been observed.

Lab. no. 8994; 5180.38 m: As sample 8992, apart from the pyrite content which is slightly lower in this sample.

Lab. no. 8995; 5183.51 m: Homogeneous sediment rich in vitrinite and inertinite (Fig. 8d). No fluorescing organic material has been observed. Large amounts of pyrite are present.

Lab. no. 8996; 5183.83 m: Similar to the previous samples; rich in vitrinite, inertinite and pyrite. No fluorescing organic material has been observed.

Analysis of mud+cutting sample extracts

The extracts are characterised by C₁₁₊ alkanes and a considerable proportion of naphthenic components (Fig. 9). The paraffinic fraction is, however, not pronounced (Fig. 10). The most abundant aromatic compounds in crude oils, phenanthrenes and methylphenanthrenes, are scarce (Fig. 11).

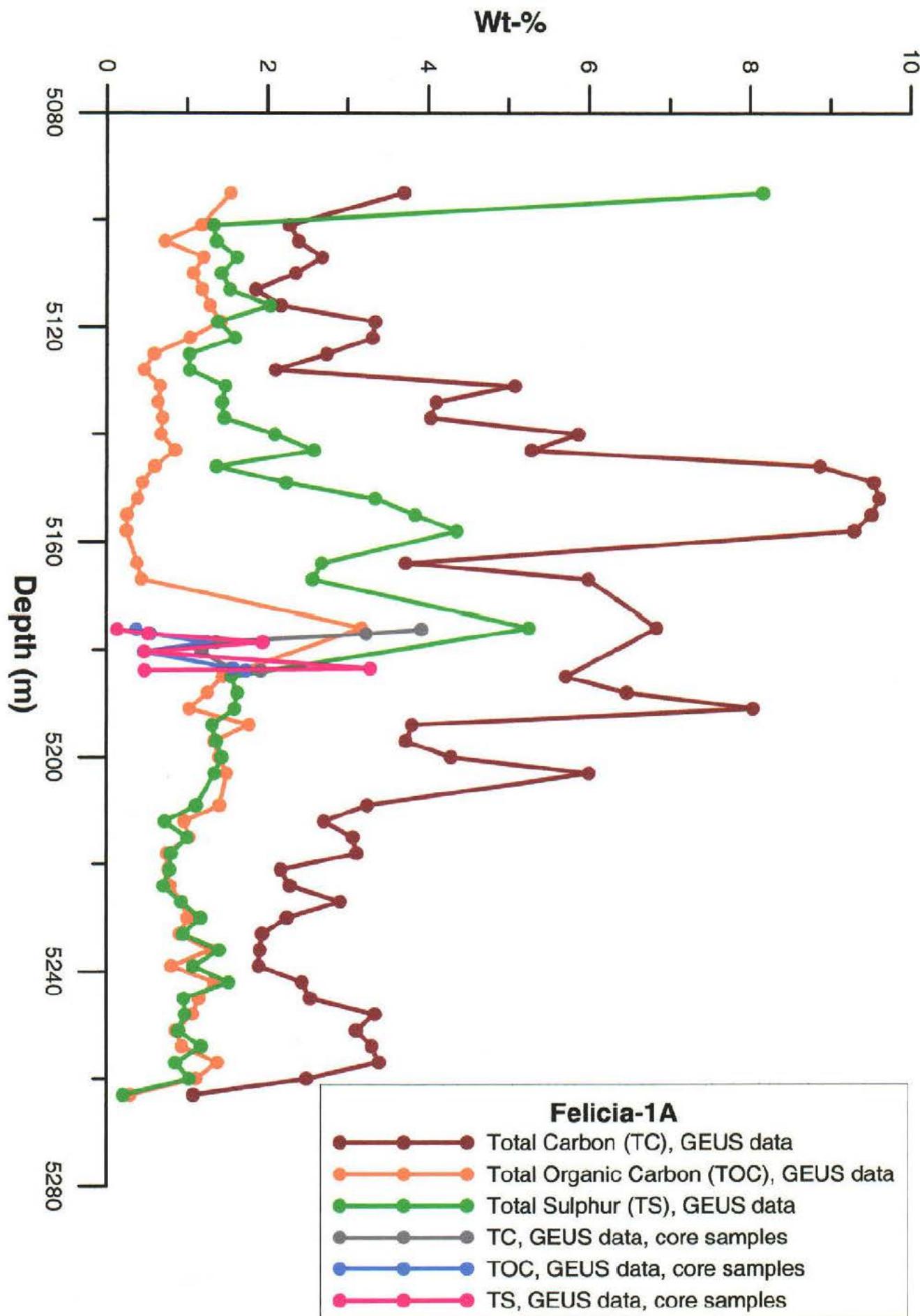


Fig. 2. Comparison of screening data from GEUS (cutting and core samples)

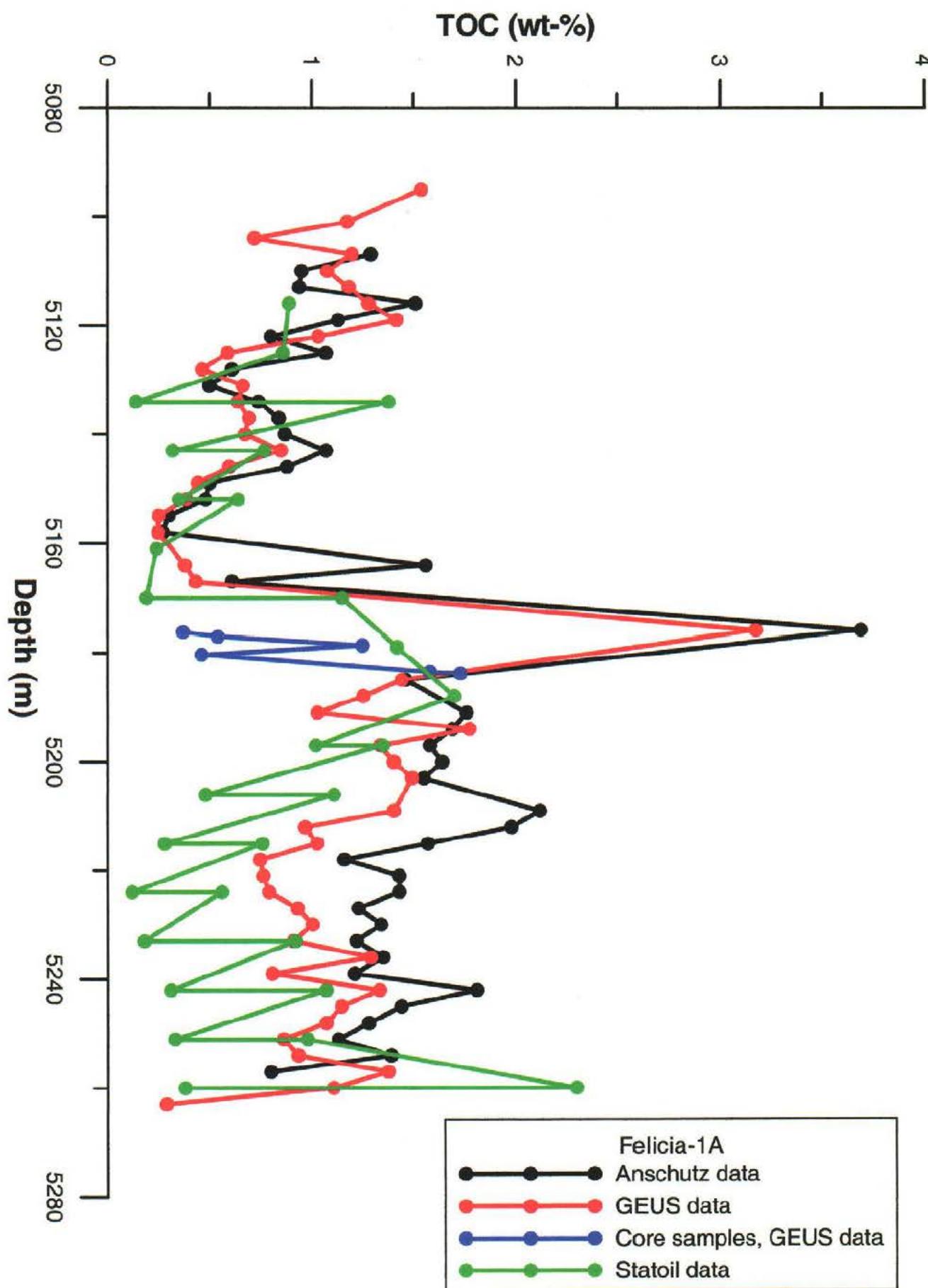


Fig. 3. Comparison of TOC data from GEUS, Anschutz and Statoil

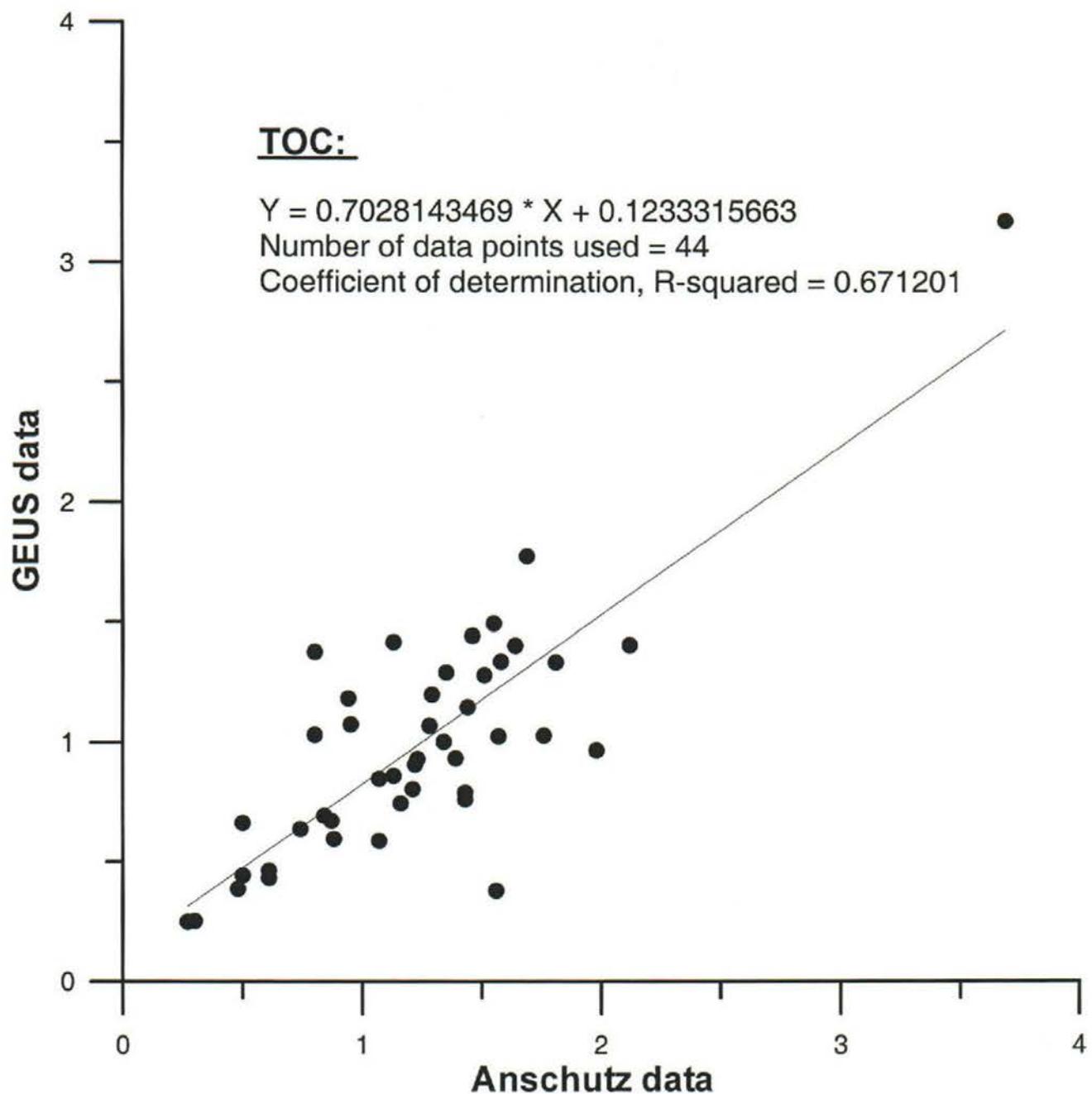


Fig. 4. A reasonable correlation exists between TOC data from GEUS and Anschutz

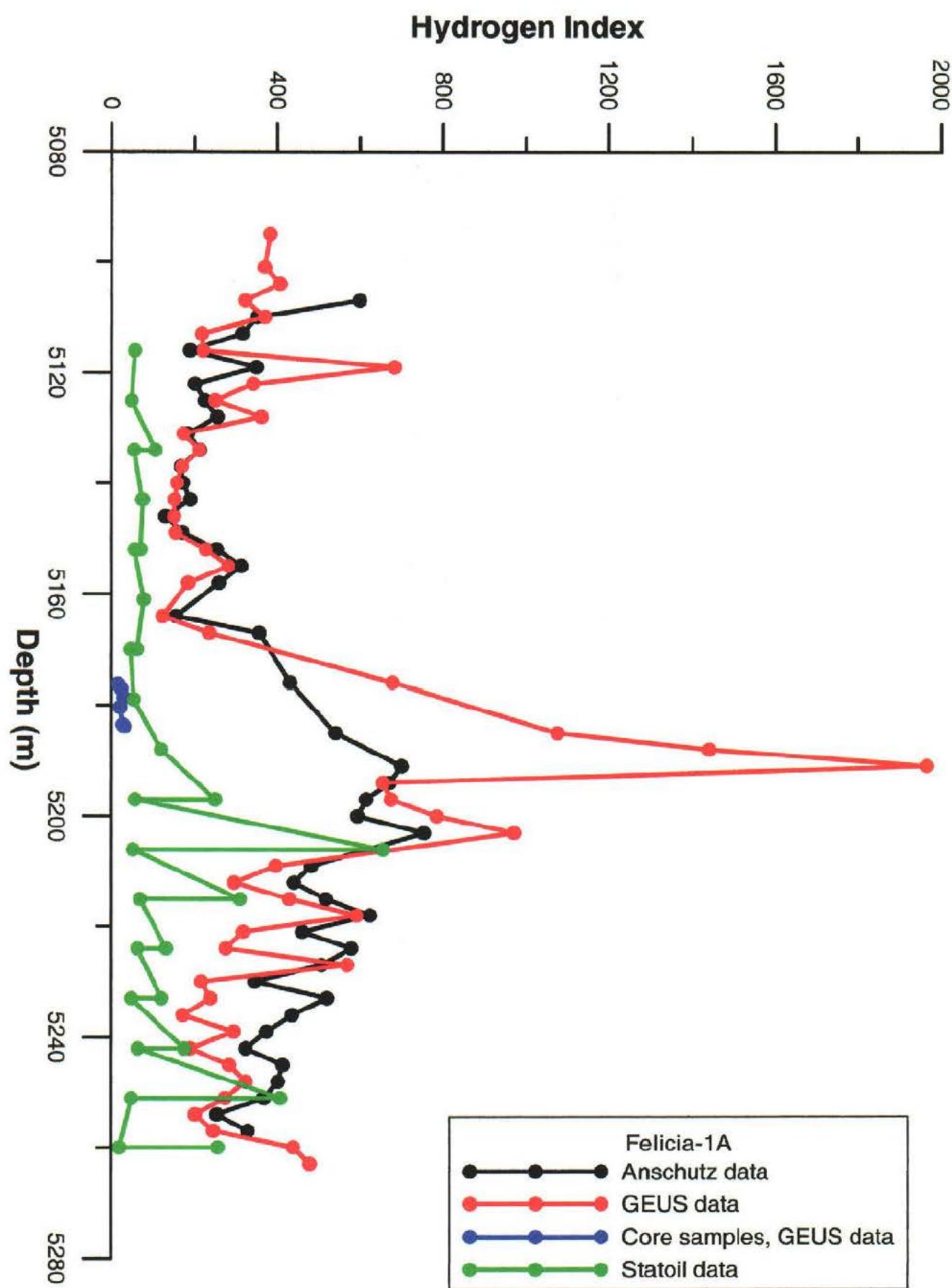


Fig. 5. Comparison of HI values from GEUS, Anschutz and Statoil. Note that significantly lower values are obtained from the core samples.

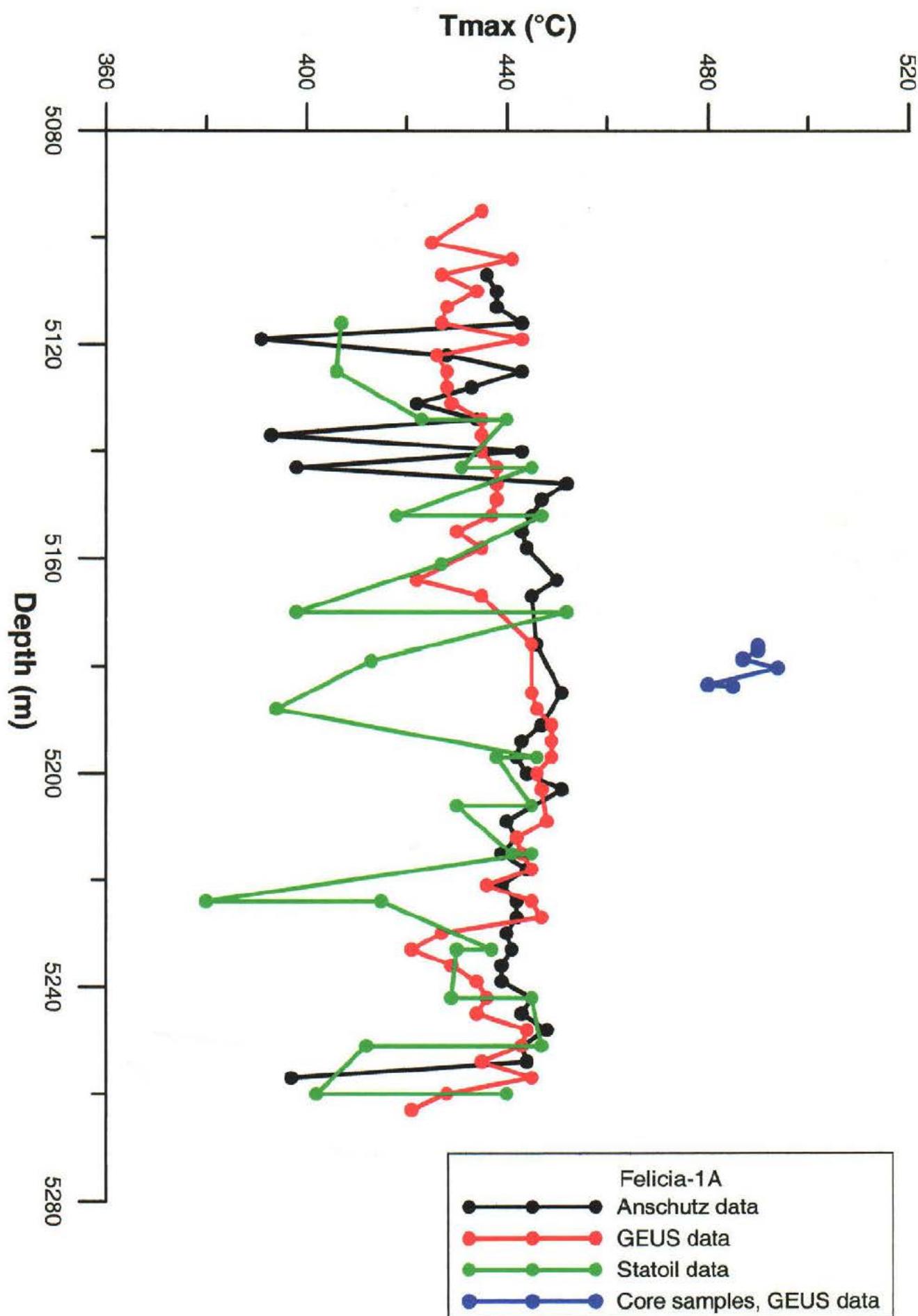


Fig. 6. Comparison of T_{\max} data from GEUS, Anschutz and Statoil. Note that the core samples yield significantly higher T_{\max} values.

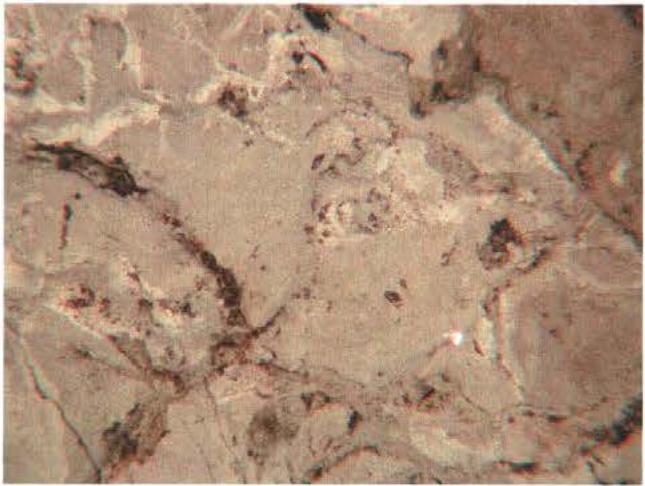


Fig. 7a: Large particle of vitrinitic-inertinitic organic matter.
Cutting sample, 5203 m (Lab. no. 8730)

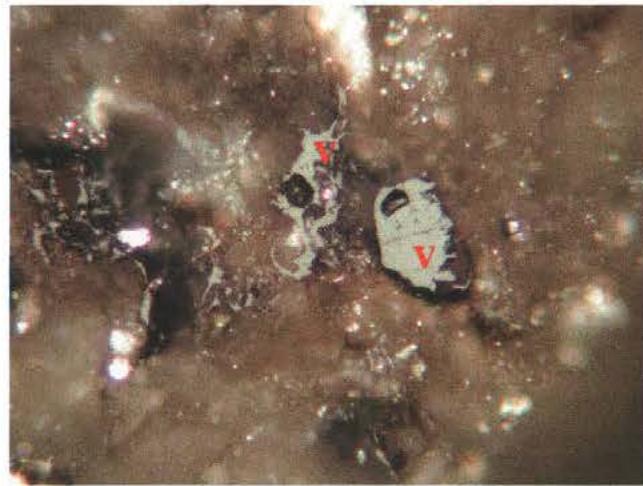


Fig. 7b: Vitrinite particles (v).
Cutting sample, 5203 m (Lab. no. 8730)

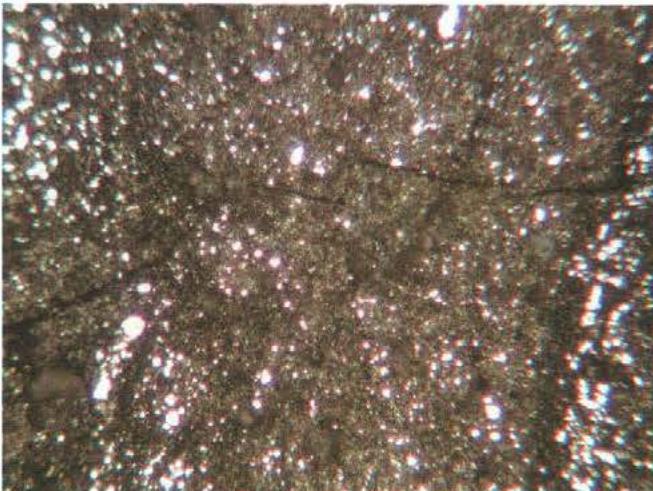


Fig. 7c: Abundance of minor pyrite particles (white).
Cutting sample, 5237 m (Lab. no. 8737)

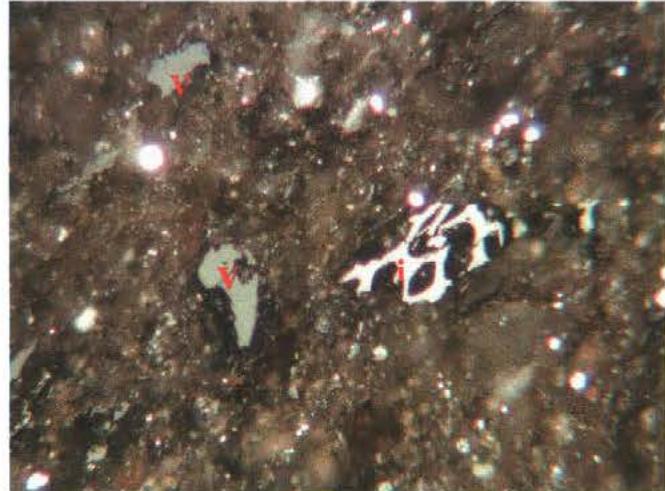


Fig. 7d: Two vitrinite particles (v) and an inertinite particle (i).
Cutting sample, 5237 m (Lab. no. 8737)

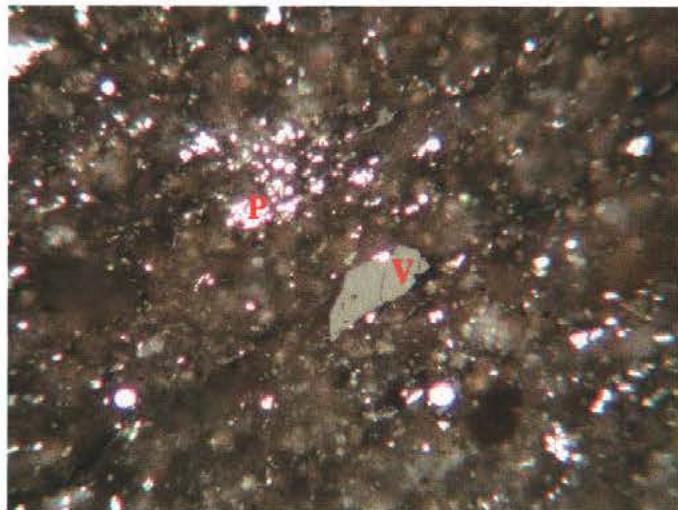


Fig. 8a: Vitrinite particle (v) and abundance of pyrite (p).
Core sample, 5177.05 m (Lab. No. 8992)

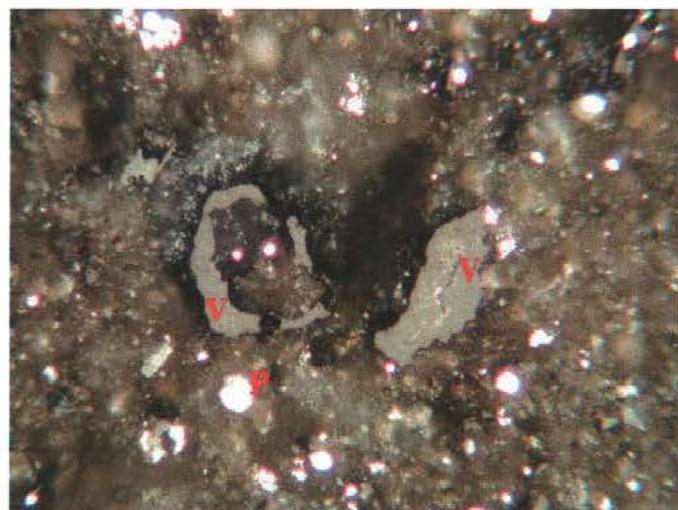


Fig. 8b: Vitrinite (v) particles and pyrite (p).
Core sample, 5178.65 m (Lab. No. 8993)

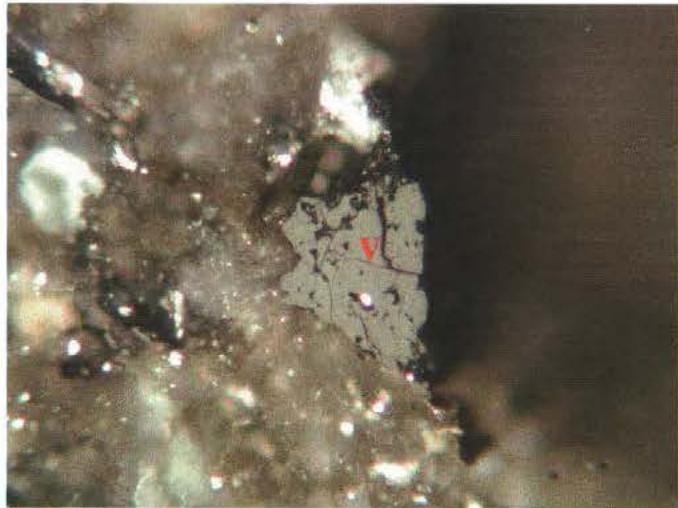


Fig. 8c: Vitrinite particle (v).
Core sample, 5178.65 m (lab. No. 8993)

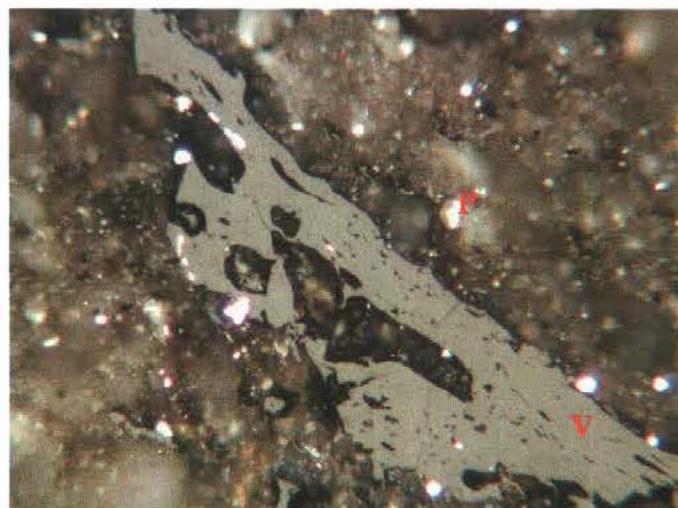


Fig. 8d: Large vitrinite particle (v) and pyrite (p).
Core sample, 5183.51 m (Lab. No. 8995)

TIC of 2003010-8815.d

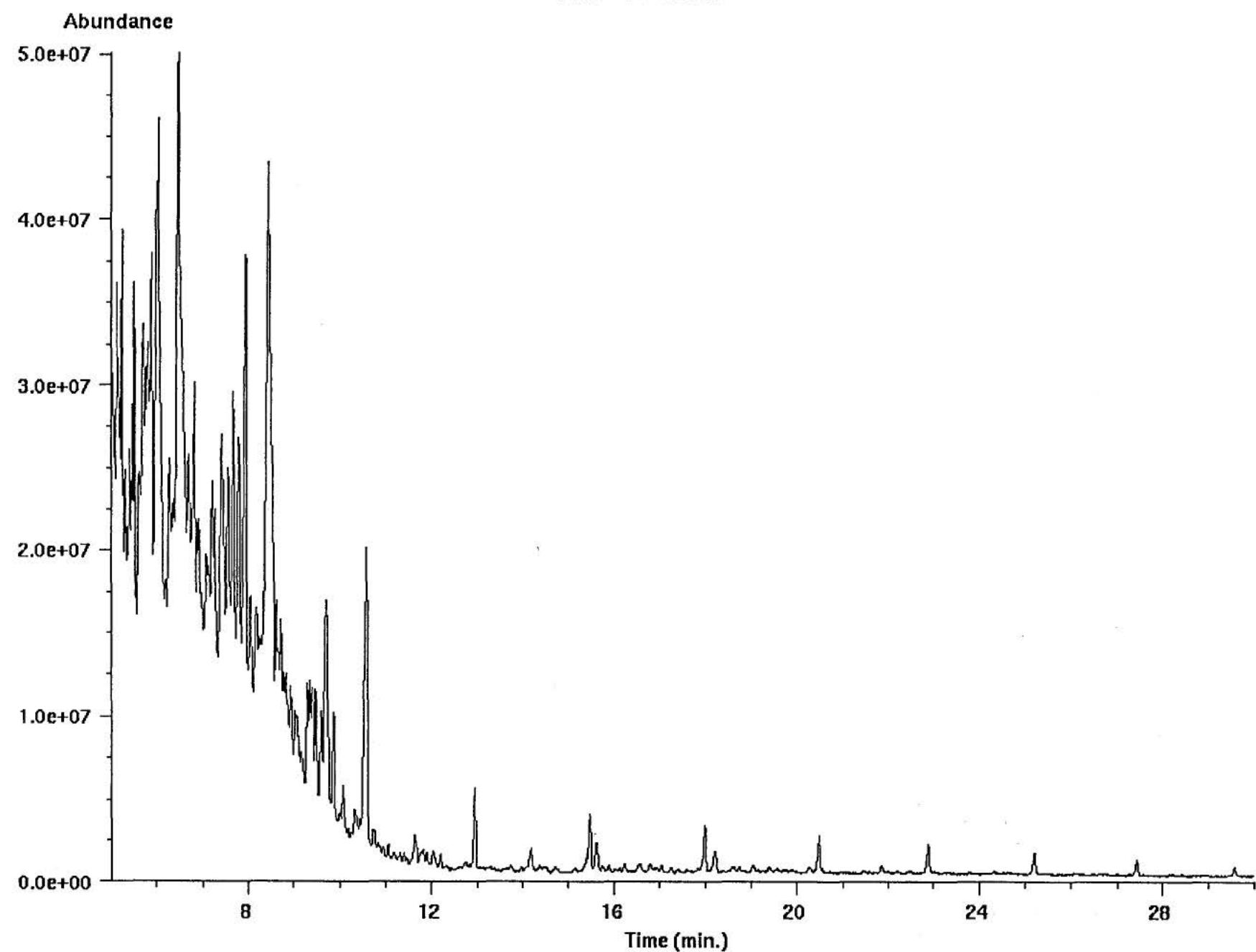


Fig. 9. Total ion chromatogram (TIC) of a cutting+mud extract (Lab. no. 8815; 5251 m).

Ion 71.00 amu from 2003010-8815.d

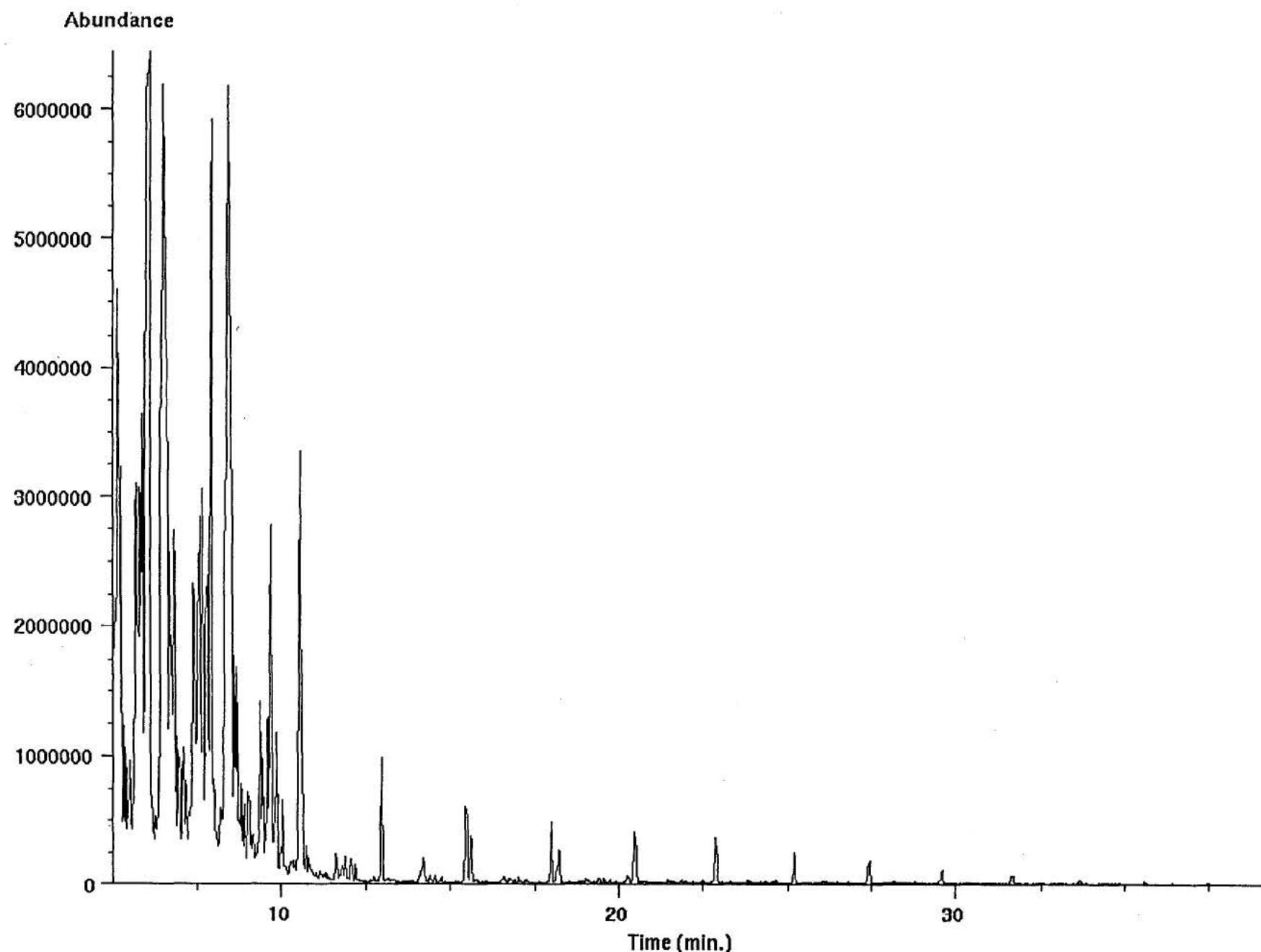


Fig. 10. Alkane fraction of a cutting+mud extract (Lab. no. 8815; 5251 m). Small amounts of mainly C₁₁₊ alkanes are present.

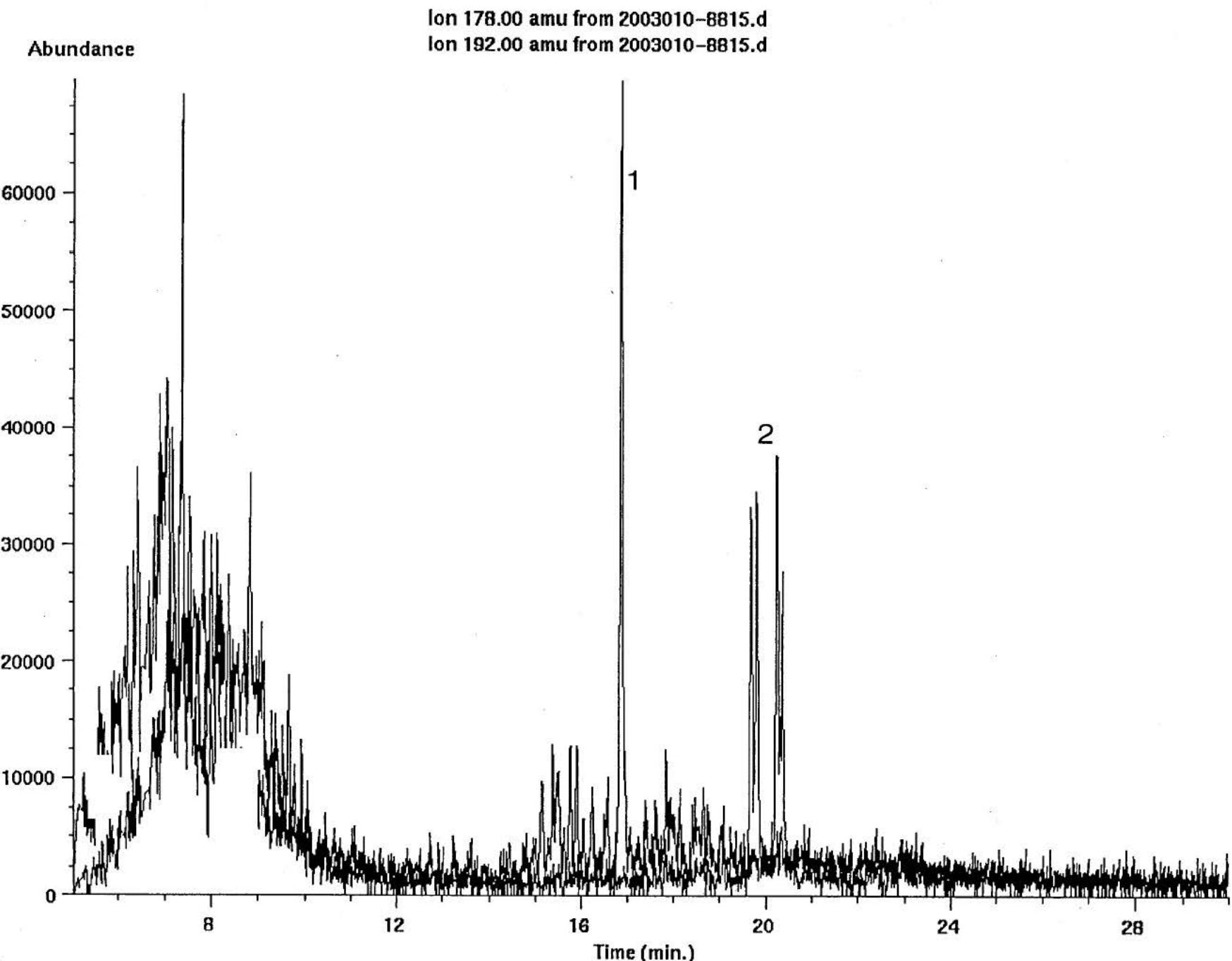


Fig. 11. Aromatic fraction of a cutting+mud extract (Lab. no. 8815; 5251 m). Only traces of aromatics are present.
1: phenanthrene; 2: methylphenanthrene.

Discussion

The results presented above suggest that despite some agreement exists between the cutting samples data, in particular between the GEUS and Anschutz data, large discrepancies occur. This is evident from comparison of both the TC, TS, TOC and HI data. It is, however, conspicuous that the core samples yield much lower HI values and considerably higher T_{max} values than the cutting samples. While the HI values of the core samples are not exceeding 32, the cutting samples yield HI values approaching 2000 (GEUS data). Since the theoretical maximum value of HI is approximately 1200, readings exceeding this number are clearly flawed. Therefore, such extraordinarily high values are way above HI values obtained from analysis of the most prolific known lacustrine source rocks containing kerogen type I (e.g. Talbot, 1988; Bohacs et al., 2000; Petersen et al., 2001; Ruble et al., 2001). The highly hydrogen-rich kerogen type I source rocks only rarely yield HI values greater than 900. The very high HI values obtained from a traditionally poor Rotliegende source rock should warrant contamination of the samples. This is strongly supported by the very low HI values of the core samples. Contamination of the core samples can be considered negligible and the results from these samples are therefore much more reliable.

The visual inspection of the samples confirm that the organic matter is composed of vitrinite (kerogen type III) and inertinite (kerogen type IV). The high HI values from the cutting samples would require the presence of very high proportions of kerogen type I organic matter, which under reflected blue light observation would display a strong yellowish fluorescence. However, neither the cutting samples nor the core samples show any degree of fluorescence.

The lack of fluorescence is, however, in good agreement with the presumably high maturity of the investigated interval. The highest T_{max} values measured on the cutting samples are $<450^{\circ}\text{C}$, and according to Hunt (1996) this corresponds approximately to a vitrinite reflectance of slightly more than $1\%R_o$. At this maturity hydrogen-rich kerogen type I or II organic matter should still fluoresce. In contrast the core samples yield T_{max} values between 480°C and 494°C , which roughly corresponds to a vitrinite reflectance range of $1.6\text{--}1.9\%R_o$. At this maturity the fluorescence behaviour of all types of organic matter has disappeared, which agrees with the observations. The low HI values suggest either completely exhaustion of the source potential or the initial presence of mainly kerogen type IV and some kerogen type III. This lends further support to the assumption that the cutting samples (all three data-sets) are contaminated by oil-based drilling mud.

From the Felicia-1 completion report (Statoil, 1988) it is documented that oil-based drilling mud was used below a depth of approximately 2000 m. The oil additive used was Shellsol D-70; a data sheet for this product is included as Appendix 1. Shellsol D-70 is predominantly composed of C_{11+} alkanes and naphthenics. This composition is similar to the composition of the cutting+mud extracts. Hence, it seems plausible to conclude, that the extraordinarily high HI values and low T_{max} values of the cutting samples is in part caused by the presence of Shellsol D-70 in the drilling mud+cutting samples.

Conclusion

The investigated core samples provide the only reliable data from the investigated interval of the Rotliegende in Felicia-1A. Based on core sample data it is concluded that the sediments do not possess any hydrocarbon generative potential, and a prolific source rock interval in this part of the Rotliegende can thus not be confirmed.

The organic matter is composed of kerogen type III and type IV, and no fluorescence from the organic material can be observed. This precludes the presence of hydrogen-rich, oil-prone organic matter in the sediments. The maturity of the organic matter is high (overmature), with inferred vitrinite reflectance values from 1.6–1.9% R_o . Hence, any original potential is exhausted at this maturity.

Very high HI values and low T_{max} values obtained from analysis of cutting samples are artificial, and are caused by the use of oil based drilling mud plus other contaminants below approximately 2000 m.

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Appendix 1

Data sheet

Shellsol D-70



Shell Chemicals

Data Sheet

IS 2.4.3, 6th Edition

12-Feb-2003

Product Name

SHELLSOL D70

Product Code

Q7712

EINECS Number

265-149-8

CAS Registry

64742-47-8

Number

Description

SHELLSOL D70 is derived from selected petroleum feedstocks which have been highly refined and reacted with hydrogen to convert aromatics to cycloparaffins. This deep hydrogenation results in products of controlled composition with very low aromatic contents, negligible reactive impurities and a low, sweet odour. SHELLSOL D70 consists predominantly of C11+ paraffins and naphthenics.

Typical properties

Property	Unit	Method	Value
Density @15°C	kg/L	ASTM D4052	0.788
Color	-	ASTM D156	+30
Distillation, IBP	°C	ASTM D86	193
Distillation, DP	°C	ASTM D86	245
Flash Point	°C	ASTM D93	73
Aromatics	% m/m	SMS 2728	0.03
Benzene	mg/kg	GC	<5
Water	%	ASTM D1744	<0.005
Sulphur (total)	mg/kg	SMS 1897	<0.5
Doctor test	-	ASTM D4952	neg.

Typical physical properties

Property	Unit	Method	Value
Vapour pressure @20°C	kPa	Calculated	0.06
Antoine Constant A #	kPa, °C	Calculated	5.99080
Antoine Constant B #	kPa, °C	Calculated	1753.00
Antoine Constant C #	kPa, °C	Calculated	221.03

	Antoine Constant:	°C	-	+40 to
	Temperature range			+215
	Pour Point	°C	ASTM D97	-50
	Heat of evaporation	kJ/kg	-	350
	Heat of combustion	kJ/kg	-	-45237
	Electrical Conductivity @20°C	pS/m	ASTM D4308	<0.085
	Dielectric Constant @20°C	-	-	2.15
	Surface tension @20°C	mN/m	ASTM D971	26
	Viscosity @25°C	mm²/s	ASTM D445	1.97
	Molecular Weight	g/mol	Calculated	174
	All properties at 20°C unless otherwise stated. The vapour pressure, between the specific temperature limits, can be calculated using the Antoine equation:			
	$\log_{10} (P) = A - B/(T+C)$ where P is the vapour pressure in kPa and T is the temperature in °C.			
Solvent properties	Property	Unit	Method	Value
	Kauri-Butanol Value	-	ASTM D1133	30
	Aniline Point (M=Mixed)	°C	ASTM D611	77
	Hildebrand Solubility	(cal/cm³)½	-	7.6
	Parameter			
	Hydrogen Bonding Index	-	-	0
	Fractional Polarity	-	-	0
	Relative Evaporation Rate (nBuAc=1)	-	ASTM D3539	0.01
	Relative Evaporation Rate (Ether=1)	-	DIN 53170	800
Safety data	Property	Unit	Method	Value
	Flash Point	°C	ASTM D93	73
	Explosion Limit: Lower	%v	DIN 51649	0.6
			U.E.L @ 100°C	
	Explosion Limit: Upper	%v	DIN 51649	5.5
			U.E.L @ 100°C	
	Auto Ignition Temperature	°C	ASTM E659	236
	Transport: ADR/RID class/label	-	-	-