Ctenidodinium continuum, *Liesbergia scarburghensis* and *Meiourogonyaulax* cf. *M. caytonensis* near the top of the Bryne Formation indicates a latest Callovian to earliest Oxfordian age.

In the southern part of the Danish Central Graben wells with deposits of the Central Graben Group are not as closely spaced as the wells with Bryne Formation sediments, and the Central Graben Group deposits exhibit fewer biostratigraphic datings. As is the case for the Bryne Formation, the lower part of the Central Graben Group succession yields poor biostratigraphic datings. A few good datings are supplied by age diagnostic spores. *Krauselisporites hyalina* in the upper part of the Lower Graben Sand Formation suggests a Bathonian age, and *Kekryphalospora distincta* lower in that formation indicates an age not younger than Early

Bajocian. A few dinoflagellate cysts have been found in the Lower Graben Sand Formation. In the upper part of the formation the Late Bajocian – Early Callovian *Pareodynia evitii* has been found below an erosive channel base, which may correlate to the major sequence boundary separating the upper and lower parts of the Bryne Formation.

In the uppermost part of the succession, in the coal-bearing Middle Graben Shale Formation, *Chytroeisphaeridia hyalina* and *Ctenidodinium sellwoodii* indicate ages not younger than Mid and Late Callovian respectively; however, the presence of *Energlynia acollaris* and *Wanaea thyssanota* may indicate an age up to Early Oxfordian. *Pareodinia prolongata* and *Rigaudella aemula*, which may range up to the Middle Oxfordian, are also found within this succession.

Samples, analytical methods and data processing

Samples

The material in this study is mainly taken from drill-cores as this procedure enables a precise correlation between sample lithology, depositional environment and organic petrography and geochemistry of the sample. If considered necessary, other sample types (sidewall cores, cuttings, extracted cuttings) were included. All core samples are indicated on the sedimentological logs presented in this bulletin.

The coal seams in the well-cores in the Søgne Basin were sampled from floor to roof (channel samples) such that, if possible, the samples represent the total thickness of the seams and also cover macroscopically visible changes in coal layering (coal facies change). A few samples were likewise collected from coaly mudstones associated with the coal seams. In the Søgne Basin a total of 110 core samples were collected, viz. 44 from West Lulu-1, 29 from West Lulu-3, 18 from Lulu-1, 13 from Amalie-1 and 6 from Cleo-1. The 6 core samples from the Cleo-1 well were supplemented with 13 sidewall core samples, 18 cuttings and 5 extracted cuttings from the Middle Jurassic interval.

Outside the Søgne Basin samples were likewise preferentially taken from drill-cores. However, due to lim-

ited coring in the Middle Jurassic interval, cuttings were also used. Core samples were collected from levels in the cores with visible disseminated organic matter or from black mudstones presumed to be rich in organic material. A total of 105 samples have been investigated, viz. 10 core samples and 20 cuttings from Alma-1x, 11 cuttings from Anne-3a, 10 core samples from Elly-3, 12 core samples and 5 cuttings from Falk-1, 12 cuttings from M-8, and 10 core samples, 13 cuttings and 2 extracted cuttings from the Skjold Flank-1 well (Fig. 1).

Organic petrographic analyses

Particulate pellets suitable for optical analyses were prepared by crushing the samples to a grain size between 63 μm and 1 mm. Approximately 20 ml of a dried (24 hrs at 60°C) homogenised sample split was embedded in epoxy. Following hardening the sample was cut vertically into two pieces and the 'new' face was ground and polished using 1/4 μm diamond powder for the final polish to obtain a smooth surface. The preparation procedure thus takes into account the grain size and density induced separation during embedding in epoxy resin.

Table 2. Macerals and minerals identified in the coal seams

Maceral group	Macerals
Vitrinite	Telinite Collotelinite Collodetrinite Gelinite Corpogelinite
Liptinite	Sporinite Cutinite Liptodetrinite Resinite Exsudatinite
Inertinite	Fusinite Semifusinite Inertodetrinite Macrinite (Char)* (Pyrolytic carbon)*
Mineral matter	Pyrite Other minerals

* detected but not counted

Vitrinite reflectance measurements

The organic maturity (rank) of the organic matter was petrographically determined by random reflectance measurements on the vitrinite maceral collotelinite. The equipment used was a Leitz MPV-SP system, which was calibrated against a standard of 0.893 %R_o. A total of 100 measurements per sample conducted in mono-chromatic light and oil immersion was the optimum; however, commonly this was not possible. The reflectance measurement procedure is in accordance with the standards outlined by Stach *et al.* (1982). A total of 25 samples have been measured.

Organic petrography

Maceral and kerogen analyses. Each sample was analysed in reflected white light and fluorescence-inducing blue light in oil immersion using a Zeiss incident light microscope and a Swift point counter. A total of 500 points (macerals, minerals) were counted in each sample. In the coal samples 14 different macerals plus pyrite and 'other minerals' were recorded (Table 2). The presence of char and pyrolytic carbon was qualitatively noted. Hard coal maceral identification follows the standards in Stach *et al.* (1982) and ICCP (1998). Maceral analyses of the coals were carried out contemporaneously with the microlithotype analysis (see below), and a total of 57 samples were investigated.

Table 3. Kerogen classification

Kerogen type	Maceral composition		Fluorescence properties	Range of Hydrogen Index (mg HC/g C_{org})	H/C atomic ratio	Peak generation (%R_o)	Generated hydro-carbons
	Major	Minor					
1	Alginite Algodetrinite Sapropelinite 1	Bacterial remnants Sapropelinite 11	Greenish yellow for alginite	> 700	> 1.5	0.6–0.9	Mainly oil
11a	Sapropelinite 11 Liptodetrinite Resinite (A+B)	Particulate liptinite (A+B) Alginite Corpogelinite	Orange to orange brown for sapropelinite 11 Yellow for resinite (A+B)	400–700	1.1–1.5	0.6–0.9 0.3–0.7 (for resinite)	Mainly oil; major gas in higher maturation (> 1.3%R_o)
11b	Particulate liptinite (mainly B) Liptodetrinite	Alginite Sapropelinite 11 Collodetrinite Humosapropelinite	Yellow for sporinite, cutinite etc.	150–400	0.8–1.3	0.7–1.1	Oil and gas
111	Vitrinite (Collotelinite, Humosa-propelinite)	Resinite Inertinite Sporinite	Dark brown for resinite	25–150	0.5–0.8	0.8–1.0 (oil) 1.0–1.5 (gas)	Mainly gas
1V	Inertinite	Vitrinite		< 25	0.5	No source of hydrocarbons	Minor gas (no source for liquid hydro-carbons)

From Mukhopadhyay *et al.* 1985

The kerogen analyses were likewise carried out by means of point-counting. The coal maceral group terminology was used to type the organic material (e.g. Hutton *et al*. 1994), and the following entities were recorded: liptinitic terrestrial organic matter (OM) and terrestrial OM, the latter divided if possible into vitrinitic OM and inertinitic OM. Intimately associated organic and mineral matter were counted as organo-mineral matrix. Pyrite and mineral matrix were also recorded.

Kerogen classification was based on the scheme developed by Mukhopadhyay *et al*. (1985), where each kerogen type among other things is characterised by a specific maceral composition and hydrogen index range (Table 3). A total of 12 kerogen analyses were carried out.

Microlithotype analyses. The same equipment described above was used for the microlithotype analysis. The analysis was only performed on the coal samples, and 500 microlithotypes were recorded in each sample. Analysis procedure and microlithotype identification follow the standards described in Stach *et al*. (1982) (Table 4), and 57 samples were investigated.

Screening analyses

A portion of all 215 samples were crushed to a grain size < 250 μm for total organic carbon (TOC) determination and Rock-Eval pyrolysis. A LECO IR-212 induction furnace was used to estimate the TOC (wt%). The samples for TOC determination were treated with HCl at 60°C to remove carbonate-bonded carbon before combustion. An untreated sample (about 10 mg) was used for Rock-Eval pyrolysis on a Delsi Rock-Eval II or Vinci Rock-Eval 5 equipment. In addition, 15 extracted coal samples from the Søgne Basin were analysed by Rock-Eval pyrolysis.

Organic geochemical analyses

Extraction

Solvent extracts were prepared by means of a Soxtec instrument using CH_2Cl_2/CH_3OH (93 vol./7 vol.) as solvent. Asphaltenes were precipitated by addition of 40-fold *n*-pentane. The maltene fractions were separated into saturated, aromatic and heteroatomic compounds by medium performance liquid chromatography (MPLC)

Table 4. Microlithotype classification

Microlithotype	Maceral Group Composition
Vitrite	vitrinite > 95%
Liptite	liptinite > 95%
Inertite	inertinite > 95%
Clarite	vitrinite+liptinite > 95%
Vitrinertite	vitrinite+inertinite > 95%
Durite	inertinite+liptinite > 95%
Trimacerite	vitrinite, inertinite, liptinite > 5%
Duroclarite	vitrinite > inertinite, liptinite
Clarodurite	inertinite > vitrinite, liptinite
Vitrinertoliptite	liptinite > vitrinite, inertinite

using a method modified from Radke *et al*. (1980b). A total of 64 samples were extracted.

Gas chromatography and gas chromatography/mass spectrometry

Saturate fractions of 64 extracts were analysed by splitless injection gas chromatography (GC) on a Hewlett Packard 5890 gas chromatograph fitted with a 25 m HP-1 WCOT column and FID. In addition the saturate fractions were analysed by coupled gas chromatography/mass spectrometry (GC/MS) using splitless injection and a Hewlett Packard 5890 series II gas chromatograph equipped with a 25 m HP-5 WCOT column and coupled to a Hewlett Packard 5971A quadropole mass spectrometer. The components emerging from the GC were scanned for preselected fragment ions (Selected Ion Monitoring, SIM), and speciel attention was paid to the m/z 191 fragment ion of hopanes and the m/z 217 and m/z 218 fragment ions of steranes.

Pyrolysis-gas chromatography

Temperature programmed pyrolysis-gas chromatography (Py-GC) was carried out on 15 solvent-extracted samples using a custom-made stainless steel pyrolysis unit coupled to a Hewlett-Packard 5890A gas chromatograph, furnished with a 50 m Chrompack CP-Sil-8CB WCOT column and FID, using direct on-column injection. The pyrolysis unit and the column were joined by 1 m precolumn, which was used for cold trapping of pyrolysis products in liquid nitrogen prior to chro-

matography. The pyrolysis temperature program (300–550°C at 20°C/min followed by 2.5 minutes at 550°C) was controlled by a custom made unit. The GC temperature program was: initial time 27 minutes at 30°C, ramp from 30–300°C at 4.5°C/min, hold at 300°C for 20 minutes.

Data analysis was carried out using HP-chemstation software. Determination of the proportions of gas-range ($C_{1–5}$) and oil-range (C_{6+}) components was carried out by construction of a horizontal baseline on blank-subtracted pyrograms at the zero-level before elution of the C_1 peak, and splitting the integrated chromatogram into a $C_{1–5}$ (gas) and a C_{6+} (oil) fraction (Pepper & Corvi 1995).

Multivariate regression analysis

Multivariate regression analysis was used to evaluate the data obtained from the petrographic and screening analyses (Rock-Eval, LECO) carried out on 54 samples from the coal seams in the Søgne Basin. Data from the previously investigated West Lulu-2 well (Petersen *et al.* 1996) were included ending up with a total of 94 samples. The variables (macerals, maceral groups, microlithotypes, TOC values) used in the multivariate calibration were the normalised data from the maceral group, maceral and microlithotype analyses together with the TOC and T_{max} values. The target parameter to which correlation was performed was the S_2 value. In a study by

Petersen *et al.* (1996) the hydrocarbon generative potential represented by S_1+S_2 was used as target parameter. However, as S_1 may vary in a way that is not entirely related to the composition of the organic material, but probably also due to primary migration, it was decided in this study only to correlate to S_2, which is taken to represent the remaining hydrocarbon generative potential. The scope of the correlation is to obtain information on the relation between the remaining generative potential and the composition of the organic matter, and thus to identify the petrographic constituents which are likely to be responsible for petroleum generation in the coal seams.

The correlation was performed with the PC software Sirius (Kvalheim & Karstang 1987) using partial least squares (PLS) regression analyses (Martens & Næs 1991). The latent variables were verified by cross validation proposed by Wold (1978), and the group memberships were calculated using the so-called 'Soft Independent Modeling of Class Analogies' (SIMCA) algorithms (Wold 1976; Kvalheim & Karstang 1992). Prior to modeling the variables were scaled to unit variances in order to avoid dominance from variables high in variance over variables low in variance but yet with significant influence on the target parameter. By doing this all variables are equally weighted with respect to variance prior to the estimation of their importance on the model, however, care must be taken not to model 'noise' from variables with very low values.

The coals of the Bryne Formation in the Søgne Basin

Sedimentological description and interpretation of the coal-bearing intervals

West Lulu-3 well

Below the carbonaceous succession there are fining upward, very fine-grained to fine-grained sandstones with small-scale trough cross-lamination and ripple cross-lamination (Figs 5, 6). Bioturbation may be present in the uppermost part of the interval. The sandstones are interpreted as fluvial channel deposits (Johannessen & Andsbjerg 1993).

The sandstones are overlain by a succession *c.* 8 m thick that is dominated by carbonaceous shales and characterised by thin coal layers or laminae, coaly debris, rootlets with occasionally coalified leaves and twigs, as well as three coal seams, named from below, seams R1, R1a and T2. Rootlets are also abundant in thin silty intercalations and in flaser-bedded heterolithic siltstone, which shows bioturbation. Seam R1 is *c.* 0.56 m thick and it appears as bright and banded coal with pyrite filling vertical cleats. The seam is gradually followed by black, carbonaceous shale. Seam R1a is only *c.* 0.30 m thick. Coal seam T2 is *c.* 0.71 m thick and contains vertical pyrite veinlets.