IKU

Confidential

INSTITUTT FOR KONTINENTALSOKKELUNDERSØKELSER

CONTINENTAL SHELF INSTITUTE

Håkon Magnussons gt. 1B — N-7000 Trondheim — Telephone (075) 15660 — Telex 55548

BA 81-6207-1

REPORT TITLE/ TITTEL

Source Rock Analysis of well 31/4-4

CLIENT/ OPPDRAGSGIVER

Norsk Hydro

RESPONSIBLE SCIENTIST/ PROSJEKTANSVARLIG

P.B. Hall

AUTHORS/ FORFATTERE

P.B Hall, M. Bjorøy, A. Mørk, J.O. Vigran

DATE/ DATO	REPORT NO./RAPPORT NR.	NO. OF PAGES/ ANT.SIDER	NO. OF ENCLOSURES/ ANT. BILAG
1.6.81	0-327/81		

SUMMARY/ SAMMENDRAG

The analysed sequence of the well was divided into zones:-

Zone A: Mostly immature claystones with some limestone with a potential as a source rock for gas.

Zone B: This zone is moderate mature and comprises mostly dark grey claystones with a good to rich potential as a source rock for oil and gas.

Zone C: This zone consists of moderate mature claystones and limestones. The dark grey claystones in this zone (assuming they are not caved) have a good potential as a source rock for oil and gas.

Zone D and E: Consists mostly of fine sandstones, and sandy limestones with a poor potential as source rocks. In zone E moderate mature carbonaceous claystones and coal have a good to rich potential as source rocks for gas and heavy oil.

contd.

KEY WORDS/ STIKKORD

Source Rock

Summary contd.

Zone F and G: Includes sandstones, claystones and siltstones. The siltstones which are moderate mature have a fair potential as a source rock for gas.

Zone H: Consists mostly of sandstone, some siltstone and coal (possibly caved). The zone is mature and the siltstone has a fair potential as source rocks for gas. The coal if indigenous has a rich potential as a source rock for gas.

EXPERIMENTAL AND DESCRIPTION OF INTERPRETATION LEVELS

Headspace gas analyses

One ml. of the headspace gas from each of the cans was analysed gas chromatographically for light hydrocarbons. The results are shown in Table la. The canned samples were washed with temperated water on 4, 2, 1 and 0.125 mm sieves to remove drilling mud and thereafter dried at 35°C.

Occluded gas

An aliquot of the 1-2 mm fraction of each sample before drying was crushed in water using an airtight ball mill, and one ml. of the headspace analysed chromatographically. The results are shown in Table lb.

Total Organic Carbon (TOC).

Picked cuttings of the various lithologies in each sample were crushed in a centrifugal mill. Aliquots of the samples were then weighed into Leco crucibles and treated with hot 2N HCl to remove carbonate and washed twice with distilled water to remove traces of HCl. The crucibles were then placed in a vacuum oven at 50°C and evacuated to 20 mm Hg for 12 hrs. The samples were then analysed on a Leco E C 12 carbon analyser, to determine the total organic carbon (TOC).

Extractable Organic Matter (EOM)

From the TOC results samples were selected for extraction. Of the selected samples, approximately 100 gm of each was extracted in a flow through system (Radke et al., 1978, Anal. Chem. 49, 663-665) for 10 min. using dichloromethane (DCM) as solvent. The DCM used as solvent was distilled in an all glass apparatus to remove contaminants.

Activated copper filings were used to remove any free sulphur from the samples.

After extraction, the solvent was removed on a Buchi Rotavapor and transferred to a 50 ml flask. The rest of the solvent was then removed and the amount of extractable organic matter (EOM) determined.

Chromatographic Separation.

The extractable organic matter (EOM) was separated into saturated fraction, aromatic fraction and non hydrocarbon fraction using a MPLC system with hexane as eluant (Radke et al., Anal. Chem, 1980). The various fractions were evaporated on a Buchi Rotavapor and transferred to glassvials and dried in a stream of nitrogen. The various results are given in Table III-VI.

Gas chromatographic analyses.

The saturated fraction was diluted with n-hexane and analysed on a HP 5730 A gas chromatograph, fitted with a 25 m OV101 glass capillary column and an automatic injection system. Hydrogen (0.7 ml/min.) was used as carrier gas and the injection was performed in the split mode (1:20).

Vitrinite Reflectance.

Samples, taken at various intervals, were sent for vitrinite reflectance measurements to Geoconsultants, Newcastle-upon-Tyne. The samples were mounted in Bakelite resin blocks; care being taken during the setting of the plastic to avoid temperatures in excess of 100°C. The samples were then ground, initially on a diamond lap followed by two grades of corundum paper. All grinding and subsequent polishing stages in the preparation were carried out using isopropyl alcohol as lubricant, since water leads to the swelling and disintegration of the clay fraction of the samples.

Polishing of the samples was performed on Selvyt cloths using three grades of alumina, 5/20, 3/50 and Gamma, followed by careful cleaning of the surface.

Reflectance determinations were carried out on a Leitz M.P.V. microphotometer under oil immersion, R.I. 1.516 at a wavelength of 546 nm. The field measured was varied to suit the size of the organic particle, but was usually of the order of 2 micron diameter.

The surface of the polished block was searched by the operator for suitable areas of vitrinitic material in the sediment. The reflectance of the

organic particle was determined relative to optical glass standards of known reflectance. Where possible, a minimum of twenty individual particles of vitrinite was measured, although in many cases this number could not be achieved.

The samples were also analysed in UV light, and the colour of the fluorescing material determined. Below, a scale comparing the vitrinite reflectance measurements and the fluorescence measurements are given.

VITRINITE REFLECTANCE R. AVER. 546 nm 1516	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10
% CARBON CONTENT DAF.	57	62	70	73	76	79	80.5	82.5	84	85.5

LIPTINITE FLUOR nm	725	750	790	820	840	860	890	940	
EXC. 400 nm BAR. 530 nm colour	G	$G/_Y$	Y	$Y/_O$	L.O.	M.O.	D.O.	$O/_R$	R
zone	1	2	3	4	5	6	7	8	9

NOTE LIPTINITE NM = NUMERICAL MEASUREMENTS OF OVERALL SPORE COLOUR AND NOT PEAK FLUORESCENCE WAVELENGTH

RELATIONSHIP BETWEEN LIPTINITE FLUORESCENCE COLOUR, VITRINITE REFLECTANCE AND CARBON CONTENT IS VARIABLE WITH DEPOSITIONAL ENVIRONMENT AND CATAGENIC HISTORY. THE ABOVE IS ONLY A GUIDE. LIPTINITE WILL OFTEN APPEAR TO PROCESS TO DEEP ORANCE COLOUR AND THEN FADE RATHER THAN DEVELOP O/R RED SHADE. TERMINATION OF FLUORESCENCE IS ALSO VARIABLE.

Processing of Samples and Evaluation of Visual Kerogen

Crushed rock samples were treated with hydrochloric and hydrofluoric acids to remove the minerals. A series of microscopic slides contain strew mounts of the residue:

T-slide represents the total acid insoluble residue.
N-slide represents a screened residue (15 meshes).
O-slide contains palynodebris remaining after flotation ($ZnBr_2$) to remove disturbing heavy minerals.
X-slides contain oxidized residues, (oxidizing may be required due to sapropel which embeds palynomorphs, or to high coalification preventing the identification of the various groups).

T and/or O slides are necessary to evaluate kerogen composition/palynofacies which is closely related to sample lithology.

Screened or oxidized residues are normally required to concentrate the larger fragments, and to study palynomorphs (pollen, spores and dinoflagellates) and cuticles for paleodating and colour evaluation.

So far visual evaluations of kerogen have been undertaken from residues mounted in glycerine jelly, and studied by Leitz Dialux in normal light (halogene) using x10 and x63 objectives. By x63 magnification it is possible to distinguish single particles of diameters about 2 and, if wanted, to make a more refined classification of the screened residues (particles >15).

The colour evaluation is based on colour tones of spores and pollen (preferably) with support from other types of kerogen (woody material, cuticles and sapropel). These colours are dependant upon the maturity, but also are under influence of the paleo-environment (lithology of the rock, oxidation and decay processes). The colours and the estimated colour index of an individual sample may therefore deviate from those of the neighbouring samples. The techniques in visual kerogen studies are adopted from (Staplin 1969 and Burgess 1974).

In interpretation of the maturity from the estimated colour indices we follow a general scheme that is calibrated against vitrinite reflectance values (R_o).

Ro	0.45	0.6	0.9	1.0	1.3
colour	2-	2	2+	3-	3
3+					
index					
Maturity	Moderate	Mature (oil window)			Condensate
intervals	mature				window

Rock-Eval Pyrolyses

100 mg crushed sample was put into a platinum crucible whose bottom and cover are made of sintered steel and analysed on a Rock-Eval pyrolyser.

RESULTS AND DISCUSSION

Light hydrocarbon analysis and lithology

On the basis of the light hydrocarbon analysis and lithology, the sequence analysed is divided into 8 basic zones.

A. 1900-2300 m
B. 2300 2360 m
C. 2360-2450 m
D. 2450-2630 m
E. 2630-2810 m
F. 2810-2930 m
G. 2930-3050 m
H. 3050-3152 m

The zones below 2450 metres are chosen partly from lithological differences, since too few headspace analyses were made to allow a subdivision on this criterion alone.

Zone A; 1900-2300 m. The lithologies in this zone are dominated by grey and grey-green claystones, with some limestones and red-brown claystones towards the bottom of this zone. C_1 - C_4 and C_{5+} gas abundances are poor to fair, wetness is low and iC_4/nC_4 values are close to unity.

Zone B; 2300-2360 m. Consists mostly of claystones with some limestone. The dominant claystone is dark grey. C_1 - C_4 gas abundances are good, and the C_{5+} generally fair. The wetness is much higher and the iC_4/nC_4 noticeably lower than in Zone A.

Cone C; 2360-2450 m is composed of a mixture of two claystones (some dark grey and light grey) plus glauconitic, sandy limestone and very calcareous sandstones. The C_1 - C_4 gas abundances are fair to good, while the C_{5+} gas abundances are poor. Wetness and iC_4/nC_4 values are similar to those in Zone B.

Zone D; 2450-2630 m is composed of claystones (mostly light grey-green with some red-brown) and micaceous, sandy limestones/calcareous sandstones and siltstones. The claystones predominate in the upper part of the

zone. C_1 - C_4 gas abundances vary from poor to good, while C_{5+} gas abundances are poor. Wetness values are higher than in zone C, probably as a result of the loss of methane before canning this predominantly sand/lime section. iC_4/nC_4 values are slightly higher than in zone C.

Zone E; 2630-2810 m is composed of sandstones with subordinate claystones including some black carbonaceous claystones and coal. C_1 - C_4 gas abundances are generally poor except for sample 2660-2690 metres, which has a good content, but C_{5+} gas abundances are generally poor. Wetness values are significantly lower, but iC_4/nC_4 values fall slightly compared with those samples in zone D.

Zone F; 2810-2930 m. Consists of claystones (mostly grey-green) and micaceous siltstones and silty, micaceous, very fine sandstones. C_1 -C_4 and C_{5+} gas abundances are poor, wetness and iC_4/nC_4 values remain generally the same as in zone E.

Zone G; 2930-3050 m. Consists predominantly of fine sandstone and grey laminated siltstones. The C_1 - C_4 and C_{5+} headspace gas abundance of one sample from this zone is poor (2960-2990 m) whilst the other is good (3020-3050 m). Wetness and iC_4/nC_4 values remain the same as in zone F.

Zone H; 3050-3152 m. Consists mostly of sandstones with some coal, the sample from the lowest horizon taken has a good abundance of C_1 to C_4 hydrocarbons and a very low wetness indicating that methane is predominant.

Total organic carbon

Zone A. Grey and grey-green claystones with poor TOC values varying from 0.4 to 0.5%. Some dark grey claystone appears at the base of this zone in sample K 6909 (2250-2300 m) with a TOC value of 1.3%.

Zone B and Zone C. Includes a large percentage of dark grey claystones with TOC values from 3.2 to 6.6%.

Zone D. Light grey (grey-green) claystones with TOC values from 0.3 to 0.9% (i.e. poor to fair). Limestones that are found in this zone vary between 0.25 and 0.5% (i.e. poor to fair).

Zone E. The black carbonaceous claystones have a maximum TOC value of 31.5% (probably includes many coal stringers). Other values recorded were less than 10%.

Zone F, G and H. The grey-green claystones have TOC values of 0.5% to 0.6% (fair). The grey siltstones have good TOC values 1.1 to 1.7%.

Extraction and chromatographic separation

Nine samples were extracted and the extractable organic matter (EOM) was chromatographically analysed. The samples from each zone are described below.

Zone A, B, C. Four samples of dark grey claystone were taken for extraction, K 6909 (2250-2300), K 6910 (2315 2330 m), K 6911 (2330-2345 m), K 6914 (2360-2375 m). These samples all show similar characteristics. They are good to rich in C_{15+} hydrocarbons, with fair to good HC/TOC values and have a large proportion of saturated hydrocarbons. They have smooth (C.P.I. near or equal to 1), unimodal normal alkane distributions from nC_{14} to nC_{35} with maxima at nC_{17} except for K 6911 which has a more pronounced front-end bias with a maximum at nC_{15}. Pristane/nC_{17} and Pristane/Phytane values are very similar. The samples are all rich in high molecular weight material (probably steranes and triterpanes) in the region from nC_{25} to nC_{35}. All these data suggest moderate mature type II kerogens.

Zone D. No samples were taken from this zone for extraction.

Zone E. Three samples were taken for extraction from this zone. K 6965 (2660-2690 m), K 6967 (2720-2750 m) and K 6969 (2780-2810). These three samples all show similar trends. All show fair abundance of extractable hydrocarbons. Sample K 6965 with the characteristics of a coal has a low HC/TOC value and is poor in extractable hydrocarbons. The other two samples have a fair to good content of total HC/TOC values. They all have a unimodal normal alkane distribution from nC_{13} to nC_{36} with a maximum at nC_{25} for K 6965 and K 6967 and at nC_{27} for the other samples. These samples have a distinct odd/even predominance with C.P.I. values between nC_{21} and nC_{31} of 1.3-1.7 , Pristane/Phytane values and Pristane/nC_{17} values are high particularly for K 6965. There is a prominent high molecular weight hump, probably comprising much cyclic material. All these data would suggest

moderate mature type III kerogens. Sample K 6965 displays many of the characteristics of a coal.

In Zone F one sample was extracted K 7344, a siltstone (2840-2870 m). This sample has a poor abundance of extractable hydrocarbons. This is found to be fair to good when normalized to organic carbon with a large proportion of saturated hydrocarbons. This sample shows a bimodal normal alkane distrubiton from nC_{12} to nC_{35} with a smaller maxima at nC_{17} and an larger at nC_{27}. The normal alkane distrubtion is relatively smooth from nC_{12} to nC_{22}, while above this it shows an odd/even predominance (C.P.I. between nC_{21} and nC_{31} of 1.3). There is a pronounced high molecular weight hump. All this data indicates a moderate mature sample with a mixed input of type III + a small algal component giving rise to the envelope around nC_{17}.

In Zone G. One sample was extracted from this zone K 7348 (2960-2990 m), which is a siltstone. It has a fair abundance of extractable hydrocarbons and a fair to good hydrocarbon content (i.e. HC/TOC). The saturated hydrocarbon gas chromatogram shows a unimodal normal alkane distribution from nC_{12} to C_{36} with a maximum at nC_{25}. This sample also has a prominent iso/anteiso alkane component. These data indicates a predominantly terrestrial input, i.e. moderate mature - early mature type III kerogen.

Examination in reflected light

The vitrinite reflectance measurements indicate a relatively uniform gradient from 1950 to 3080 metres.

Seventeen samples were analysed in white and ultra-violet reflected light. Each sample is described and information from the analyses, i.e. vitrinite reflectance values and fluorescence colours are given.

K 6902, 1900-1950 m : Shale, Ro = 0.31(3)

The sample has a low organic content with bitumen specks and wisps. There are inertinite and reworked particles, but only two vitrinite wisps were located. UV light shows a yellow-orange fluorescence from spores and a trace only of exinite.

K 6905, 2050-2100 m : Shale and Carbonate, Ro = 0.42(2)

The sample has a very low organic content, with a few inertinite and reworked particles, traces of bitumen wisps and one vitrinite particle located. UV light shows a yellow-orange fluorescence from spore specks, and a trace only of exinite.

K 6906, 2100-2150 m : Shale, Ro = 0.31(3)

Bitumen wisps and low content of inertinite and reworked particles are present in this sample. Only two vitrinite wisps were located. UV light shows a yellow-orange fluorescence from spores and hydrocarbon specks, and a trace only of exinite.

K 6909, 2250-2300 m : Shale and Carbonate, Ro = 0.52(1)

The sample shows variable bitumen staining, with a few cuttings quite heavily stained. There is a low content of inertinite and reworked particles, with only one vitrinite wisp located. UV light shows a yellow fluorescence from spores and hydrocarbon specks and a moderate exinite content.

K 6910, 2300-2315 m : Shale and Subordinate Carbonate, Ro = 0.50(9)

The sample shows localised bitumen staining and has bitumen wisps, a low to moderate content of inertinite and reworked particles, with traces of vitrinite wisps. UV light shows a yellow and yellow-orange fluorescence from spores and a low to moderate exinite content.

K 6911, 2315-2330 m : Shale, Ro = 0.40(12)

Most cuttings in this sample show strong bitumen staining and stringers, and are rather pyritic. There is a low content of inertinite and reworked particles with traces of true vitinite particles. UV light shows a yellow and yellow-orange fluorescence from spores and hydrocarbon specks and a moderate exinite content

K 6914, 2360-2375 m : Shale, Ro = 0.42(9)

The sample shows bitumen staining and has bitumen wisps and is rather pyritic. There is a low content of small particles of inertinite and reworked particles with traces only of true vitrinite particles. UV light shows a yellow and yellow-orange fluorescence from spores, and a moderate content of exinite.

K 6957, 2435-2450 m : Shale, Ro = 0.36(21)

The sample shows strong bitumen staining and has bitumen wisps. There is a moderate content of inertinite and reworked particles with subordinate vitrinite particles and wispy particles. UV light shows a yellow/orange fluorescence from spores and hydrocarbon specks and a low exinite content.

K 6961, 2540-2570 m : Calcareous Siltstone, Ro = 0.40(22)

The sample shows localised bitumen staining and bitumen wisps, otherwise there is a low content of vitrinite wisps and inertinite and reworked particles in about equal proportions. UV light shows a yellow to light orange fluorescence from spores and a low exinite content.

K 6963, 2600-2630 m : Mixed Shale and Siltstone lithologies, Ro = 0.46(22)

The sample has a low organic content with some bitumen wisps and staining. There are some inertinite particles with a small proportion of vitrinite wisps and wispy particles. UV light show a light orange fluorescence from spores and hydrocarbon wisps, and a low exinite content.

K 6965, 2660-2690 m : Shale, Siltstone and Coal traces, Ro = 0.56(22)

The sample has a moderate organic content, and the shale is bitumen stained with good vitrinite wisps. Siltstone has mostly inertinite particles. The coal is normal and is inertinite rich. UV light shows a light orange fluorescence from spores and a low exinite content.

K 6967, 2720-2750 m : Siltstone and Shale, Ro = 0.51(13)

The sample has a low organic content, with bitumen wisps and staining in the shale cuttings. Mostly consists of inertinite and reworked particles,

but there are a few vitrinite wispy particles. UV light shows a yellow-orange and mid-orange fluorescence from spores, and a low exinite content.

K 6969, 2780-2810 m : Shale and Siltstone, Ro = 0.44(18)

The sample shows bitumen staining and wisps in the shale. There is a low content of inertinite particles with traces of true vitrinite wisps. UV light shows a light orange fluorescence from spores, and a moderate to rich exinite content.

K 7344, 2840-2870 m : Shale and Siltstone, Ro = 0.54(13)

The sample has a low organic content, with bitumen wisps in the shale. There are a few inertinite and reworked particles with subordinate vitrinite particles. UV light shows a yellow-orange to light orange fluorescence from spores and a moderate to rich exinite content.

K 7346, 2900-2930 m : Calcareous Siltstone, Ro = 0.44(20)

The sample shows bitumen staining and wisps. There is a low to moderate organic content with inertinite and reworked particles dominant, and subordinate vitrinite wispy particles. UV light shows a yellow-orange and light orange fluorescence from spores and a rich exinite content.

K 7348, 2960-2990 m : Shale and Siltstone, Ro = 0.52(20)

The sample shows light bitumen staining with some bitumen wisps. There is a low to moderate organic content with inertinite and reworked particles and subordinate true vitrinite wisps and particles. UV light shows a light and mid-orange fluorescence from spores and hydrocarbon specks and a low exinite content.

K 7352, 3080-3110 m : Shale and Siltstone, Ro = 0.60(21)

The sample has bitumen staining and wisps, with a moderate content of inertinite particles and subordinate but good content of vitrinite wisps. UV light shows a light orange fluorescence from spores and a moderate exinite content.

Investigation of kerogen in transmitted light

Nine samples from this well were processed for isolation of disperse organic matter. Four samples in the interval 2250 to 2375 m, and five samples from 2660 to 2960 m.

Samples 2250-2330 m

The residues seem dominated by strongly sapropelized herbaceous material dominantly of cuticular nature. The amorphous material has been evaluated as including approximately two thirds of sapropel. However, the appearance as dense aggregates makes distrinction of their relative proportions rather arbitrary.

Colour index: $^{1}/1+$

Maturation: The pollen grains observed are of yellow to yellow-green colour. The residues are fairly rich and the true maturation index may be closer to 1+ for material that has potential for gas and oil.

Sample 2360-2375 m

The residue is dominated by terrestrial material and resembles the residues above but seem either derived from a poorer interval or represents a poor lithology polluted by caved material from the above interval.

Maturation: as above, colour index $^{1}/1+$ for poorly preserved material that has potential for gas and oil.

Sample 2660-2690 m

Amorphous material is dominant in this residue. The terrestrial input represents about 20% and is distinguished by containing fairly well preserved palynomorphs.

Colour index: 1+ or $^{1+}/2-$

Maturation: The pollen grains are of somewhat deeper yellow colour than in the samples above, immature to moderate mature.

Sample 2720-2750 m

Amorphous material dominates but there is apparently a stronger terrestrial influx including abundant spores cuticles and woody matter. Since the material

is recorded partly as dense aggregates, the relative amount of true amorphous material is somewhat arbitary. We do not exclude that the amorphous material may represent caved lithologies at this level.

Colour index: $^{1+}/2-$
An immature to moderate mature interval with potential for oil and gas.

Sample 2780-2810 m

Terrestrial remains dominate and includes a rich pollen/spore assemblage, but mainly fragments of woody nature. About one third of the residue seems of true amorphous (algal) nature. Pyrite framboids are abundant.

Colour index: $^{1+}/2-$. 1+ is considered to represent caved material. The potential seems to be mainly for gas.

Sample 2840-2870 m

The residue probably represents a mixture of Late Jurassic marine lithologies (dinsflagellate cysts) and some older Jurassic pollen. The main character distinguishing the residue is the presence of abundant structured woody material (equivalent to fusinite).

We suggest a rather poor lithology dominated by terrestrial material.

Colour index: $^{2-}/2$ probably based on somewhat oxidised material.
A moderate mature sample with potential for gas ?only.

Sample 2960-2990 m

Sapropelised terrestrial and true amorphous sapropel has been evaluated as equally important in this residue. The estimate is somewhat arbitrary since the remains occur together as dense aggregates.

Colour index: 2-
A moderate mature formation with potential for oil and gas.

Rock-Eval Pyrolyses

A total of 9 samples (the same samples which were taken for extraction) from the analysed sequence in this well were taken for Rock-Eval analyses. The results are discussed below.

Zone A. One sample K 6090, 2250-2300 metres (a dark grey claystone) was taken from this zone. The T_{max} value indicates an immature kerogen. The production index is fairly high and probably indicates some migrated hydrocarbons from zone B. The similar and low oxygen and hydrogen indices indicate a mostly type III kerogen.

Zone B and Zone C. Three samples were taken from these two zones. All show similar characteristics. The T_{max} and production index values indicate an immature sample. The hydrogen index is high and oxygen index low, and the petroleum potential is high, suggesting that the organic matter in these samples is predominantly type II kerogen. These samples have a good potential as source rocks for oil and gas.

Zone D. No samples were analysed from this zone.

Zone E. Three samples were analysed from this zone. K 6965 (2660-2690 m), K 6967 (2720-2750 m), K 6969 (2780-2810 m). These first samples have noticeably higher T_{max} values than those from zone B and C. This is probably due to the difference in the kerogen type as well as increased maturity. Hydrogen indices are lower than zone B and C and indicate with the low production indices that these samples are immature to moderate mature type III kerogens. The petroleum potential of the first two samples is high (particularly the first) with a good potential as a source rock for gas.

In zone F one sample was analysed K 7344 (2840-2870 m). The T_{max} value is lower than those above in zone E, however, the peak of this sample is very broad and the value is probably inaccurate. The production index is higher than in the zones above and the sample is probably moderate mature. The hydrogen and oxygen indices are characteristic of a predominantly type III kerogen. The sample has a fair potential as a source rock for gas.

In zone G one sample was analysed, K 7348 (2960-2990). The sample has a T_{max} indicating a moderate mature kerogen. The hydrogen index and oxygen index indicate a predominantly type III kerogen. The sample has a fair potential as a source rock for gas.

CONCLUSIONS

The maturity of the analysed samples from the well 31/4-4 is mainly based on vitrinite reflectance, spore fluorescence, kerogen colour in transmitted light and T_{max} values from Rock-Eval analysis. The richness of the samples is based on TOC, Rock-Eval pyrolyses with additional evidence from light hydrocarbon concentrations and the abundance of extractable C_{15+} hydrocarbons. Source rock quality is based mainly on Rock-Eval pyrolyses with additional evidence coming from visual kerogen examination and from the saturated hydrocarbon gas chromatograms.

Zone A, 1900-2300 m: Consists mostly of claystones with some limestones. The zone is mostly immature and mostly diagenetic methane was found. Samples were analysed only for Headspace and TOC. TOC values indicate that this zone has a poor potential as a source rock.

Zone B, 2300-2360 m: Consists of up to 70% dark grey claystone. The dark grey claystones are rich in TOC (up to 6.6%) and from visual kerogen analysis consists mostly of strongly sapropelized herbaceous material. Rock-Eval pyrolysis indicates a type II kerogen. Light hydrocarbons are rich in this zone and wetness and iC_4/nC_4 ratio indicates an immature to moderate mature zone, as does Rock-Eval, visual kerogen analysis and vitrinite reflectance. The analyses indicate that this zone has a good to rich potential as a source rock for oil and gas.

Zone C, 2360-2450 m: Dark grey claystones in this zone may well be caved material. The other major lithologies include light grey claystones and sandy limestones. The dark grey claystone has the same characteristics as in zone B, the other lithologies have a poor potential as source rocks.

Zone D, 2450-2630 m: This zone is composed of a mixed claystone lithology (mostly light grey-green, with some red-brown) and micaceous sandy limestones/calcareous sandstones and siltstones. The claystones which have poor to fair TOC values are concentrated in the upper part of this zone.

Zone E, 2630-2810 m: Is composed mostly of sandstones and some claystones including some black carbonaceous claystones with coal. The carbonaceous claystones are rich in TOC, with high values (e.g. 31.5%) including coal stringers. Rock-Eval pyrolyses of these indicate a predominantly type

III kerogen, while visual kerogen analysis indicates mostly amorphous material with only 20% recognizable terrestrial material. Extractable hydrocarbon analysis indicates a predominantly terrestrial input which is moderate mature. Headspace analysis displays high methane contents, presumably derived from the predominantly terrestrial material in the carbonaceous claystones and coal(s). The analyses indicate that these claystones are moderate mature and have a good to rich potential as source rocks for gas and heavy oil.

Zone F, 2810-2930 m. The lithologies in this zone include grey-green and red claystones, grey siltstones and very fine sandstones. Of these lithologies the TOC values of the siltstones show most promise, with a good amount of organic carbon. The Rock-Eval analysis of this sample indicates a predominantly type III kerogen which from visual studies is rich in fusinite. Vitrinite reflectance and Rock-Eval T_{max} indicates a moderate mature zone. Extractable hydrocarbon analysis indicates a largely terrestrial input with only a fair content of extractable hydrocarbons. The analyses indicate that this zone has a poor to fair potential as a source rock for gas.

Zone G, 2930-3050 m: Consists mostly of fine sandstones and grey (in part laminated) siltstones. The siltstones have a good content of TOC (1.7% TOC). Rock-Eval analysis indicates that a predominantly type III kerogen is present which, from visual studies is composed of an equal mixture of sapropelized terrestrial and true amorphous material. Vitrinite reflectance, spore coloration and T_{max} values indicate a moderate mature to early mature sample. Extractable hydrocarbon analysis indicates a predominantly terrestrial input, with a fair to good content of extractable hydrocarbons. The analyses indicate a zone with a fair to good(?) potential as a source rock for gas and heavy oil.

Zone H, 3050-3152 m: This zone consists mostly of sandstones with some coal (which may be caved). No samples were analysed from this zone, except for TOC and Headspace analysis. These analyses show some grey siltstone (which may be caved) with a good TOC value, and the headspace gas analyses of the sample from the base of this zone is very rich in methane which is probably derived from the coal.

IKU

TABLE I a.

CONCENTRATION (ul Gas / kg Rock) OF C1 - C7 HYDROCARBONS IN HEADSPACE.

IKU No.	DEPTH (m)	C1	C2	C3	iC4	nC4	C5+	SUM C1-C4	SUM C2-C4	WET-NESS (%)	iC4 / nC4
K6902	1950	162	5	6	2	3	9	178	16	8.99	.67
K6903	2000										
K6904	2050	1371	23	18	3	7	13	1422	51	3.59	.43
K6905	2100	372	5	11	3	3	13	394	22	5.58	1.00
K6906	2150	659	20	38	10	10	67	737	78	10.58	1.00
K6907	2200	635	12	31	6	6	8	690	55	7.97	1.00
K6908	2250	821	112	211	36	76	21	1256	435	34.63	.47
K6909	2300	7194	1870	4022	695	2040	1863	15821	8627	54.53	.34
K6910	2315	12904	3278	5957	869	2441	2229	25449	12545	49.29	.36
K6911	2330	2627	4978	6858	958	2358	1940	17779	15152	85.22	.41
K6912	2345	10549	2533	4299	660	1730	1923	19771	9222	46.64	.38
K6913	2360	6068	1528	2640	432	991	770	11659	5591	47.95	.44
K6914	2375	1042	269	606	127	266	223	2310	1268	54.89	.48
K6915	2390	1748	605	1445	264	607	576	4669	2921	62.56	.43
K6916	2405	5811	1656	3084	449	992	944	11992	6181	51.54	.45
K6917	2420	1697	447	659	97	175	117	3075	1378	44.81	.55
K6957	2450	5871	1288	1591	177	317	172	9244	3373	36.49	.56
K6959	2500	77	36	88	17	26	19	244	167	68.44	.65
K6961	2570	505	230	608	114	221	166	1678	1173	69.90	.52
K6963	2630	1082	579	1237	195	430	135	3523	2441	69.29	.45
K6965	2690	9746	626	572	74	170	255	11188	1442	12.89	.44
K6967	2750	688	73	80	12	26	47	879	191	21.73	.46
K6969	2810	556	192	243	29	80	89	1100	544	49.45	.36
K7344	2870	328	43	90	24	70	95	555	227	40.90	.34
K7346	2930	28	25	63	7	19	10	142	114	80.28	.37

IKU

TABLE I a.

CONCENTRATION (ul Gas / kg Rock) OF C1 - C7 HYDROCARBONS IN HEADSPACE.

IKU No.	DEPTH (m)	C1	C2	C3	iC4	nC4	C5+	SUM C1-C4	SUM C2-C4	WET-NESS (%)	iC4 --- nC4
K7348	2990	43	23	32	3	7	3	108	65	60.19	.43
K7350	3050	1952	1543	2873	285	719	400	7372	5420	73.52	.40
K7352	3110	335	78	85	7	18	16	523	188	35.95	.39
K7354	3152	55782	6570	2288	116	251	209	65007	9225	14.19	.46

IKU

LITHOLOGY AND TOTAL ORGANIC CARBON MEASUREMENTS

TABLE NO.: II
WELL NO.: 31/4-4

Sample	Depth	TOC	Lithology
K 6902	1950 m	0.46	grey Claystone, yellow-grey Claystone
K 6904	2050 m	0.43	grey-green Claystone
			sm.am. Marl
K 6905	2100 m	0.48	80% grey Claystone
			20% white and grey Limestone
			sm.am. Glauconite
K 6906	2150 m	0.53	75% grey Claystone
		0.14	25% grey-green-brown Limestone
K 6907	2200 m	0.46	80% grey Claystone
			10% white Limestone
			10% grey calcareous Claystone
K 6908	2250 m		50% grey Claystone
			30% grey calcareous Claystone
			15% red Claystone
			5% white Limestone
K 6909	2300 m	0.74	35% grey Claystone
		1.30	30% dark grey Claystone
			25% red Claystone
			10% light grey, white Limestone
K 6910	2315 m	0.62	40% grey Claystone
		5.40	40% dark grey Claystone
			10% red Claystone
			10% light grey to white Limestone

IKU

LITHOLOGY AND TOTAL ORGANIC CARBON MEASUREMENTS

TABLE NO.: II

WELL NO.: 31/4-4

Sample	Depth	TOC	Lithology	
K 6911	2330 m		15%	grey Claystone
		6.56	70%	dark grey Claystone
			10%	white Limestone
			5%	red Claystone
K 6912	2330-45 m	0.69	25%	light grey Claystone
		5.98	60%	dark grey Claystone
			10%	white Limestone
			5%	red Claystone
			occ.	Pyrite
K 6913	2345-60 m		20%	light grey Claystone
			65%	dark grey Claystone
			10%	red Claystone
			5%	white Limestone
			occ.	Coal fragments?
			occ.	Pyrite
K 6914	2360-75 m		30%	light grey Claystone
			60%	dark grey Claystone
			occ.	red Claystone
			10%	grey-white glauconitic Limestone
			occ.	Pyrite
K 6915	2375-90 m	0.37	35%	light grey Claystone
		4.71	40%	dark grey Claystone
			5%	red Claystone
			20%	glauconitic, light Limestone
			occ.	Pyrite

IKU

LITHOLOGY AND TOTAL ORGANIC CARBON MEASUREMENTS

TABLE NO.: II
WELL NO.: 31/4-4

Sample	Depth	TOC	Lithology
K 6916	2405 m	0.44	30% light grey Claystone
			10% dark grey Claystone
		0.53	60% sandy Limestone
			sm.am. Pyrite
			sm.am. red Claystone
K 6917	2420 m	1.49	40% light grey, green Claystone
		3.15	30% dark, micaceous, grey Claystone
		0.69	20% light sandy Limestone
			5% red Claystone
			occ. Pyrite
K 6957	2435-50 m	0.88	60% light grey (green) Claystone
		0.89	20% red, brown Claystone
			20% micaceous Limestone
K 6959	2480-2510 m	0.55	50% grey-green Claystone
		0.28	45% sandy, micaceous Limestone
			5% red-brown Claystone
K 6961	2450-70 m	0.74	20% light grey Claystone
		0.25	75% micaceous, sandy Limestone/ highly calcareous, very fine Sandstone
			5% red-brown Claystone
K 6963	2600-30 m	0.33	20% light grey Claystone
		0.48	80% micaceous Sandstone/highly calcareous, very fine Sandstone

01/E/3/jlh

IKU

LITHOLOGY AND TOTAL ORGANIC CARBON MEASUREMENTS

TABLE NO.: II
WELL NO.: 31/4-4

Sample	Depth	TOC	Lithology	
K 6965	2660-90 m		15%	light grey-green Claystone
		31.50	5%	black, highly carbonaceous Claystone - interlaminated with Coal fragments
			80%	highly, calcareous, micaceous, very fine Sandstone
K 6967	2720-50 m		75%	medium Quartz, Sandstone
		0.51	10%	light grey, green Claystone
		5.46	15%	dark, carbonaceous Claystone
			sm.am.	sandy Limestone
K 6969	2780-2810	0.36	85%	medium, Quartz Sandstone, calcareous
		0.36	5%	light grey, green Claystone
		1.64	10%	dark Claystone
K 7344	2870 m	0.58	70%	grey, green Claystone
		0.27		red Claystone
		1.14	30%	grey, micaceous Siltstone
K 7346	2930 m	0.53	20%	grey, green Claystone
		0.53	80%	silty, grey, micaceous Sandstone
K 7348	2990 m	1.68	65%	grey, laminated Siltstone
			35%	Siltstone, as above
K 7350	3050 m		70%	Siltstone
			30%	Sandstone, as above
K 7352	3110 m	1.31	25%	grey Siltstone
			75%	Sandstone

IKU

LITHOLOGY AND TOTAL ORGANIC CARBON MEASUREMENTS

TABLE NO.: II

WELL NO.: 31/4-4

Sample	Depth	TOC	Lithology
K 7354	3152 m		90% Sandstone 5% Coal 5% Siltstone, as above

01/E/5/jlh

IKU

T A B L E : III

WEIGHT OF EOM AND CHROMATOGRAPHIC FRACTIONS

IKU-No	DEPTH (m)	Rock Extr. (g)	EOM (mg)	Sat. (mg)	Aro. (mg)	HC (mg)	Non HC (mg)	TOC (%)
K-6909	2300	9.4	5.9	2.6	1.2	3.8	2.1	1.3
K-6910	2315	24.0	31.4	9.0	7.3	16.3	15.1	2.6
K-6911	2330	22.1	69.7	19.0	16.6	35.6	34.1	5.8
K-6914	2375	12.2	17.2	4.9	3.6	8.5	8.7	2.8
K-6965	2690	34.6	27.9	3.2	2.2	5.4	22.5	2.5
K-6967	2750	41.9	14.5	4.7	2.0	6.7	7.8	.8
K-6969	2810	19.5	6.1	1.8	1.1	2.9	3.2	.8
K-7344	2870	78.4	13.8	5.3	2.4	7.7	6.1	.7
K-7348	2990	59.8	21.5	4.3	4.1	8.4	13.1	.8

IKU

T A B L E : IV

CONCENTRATION OF EOM AND CHROMATOGRAPHIC FRACTIONS

(Weight ppm of rock)

IKU-No	DEPTH (m)	EOM	Sat.	Aro.	HC	Non HC
K-6909	2300	628	277	128	404	223
K-6910	2315	1308	375	304	679	629
K-6911	2330	3154	860	751	1611	1543
K-6914	2375	1410	402	295	697	713
K-6965	2690	806	92	64	156	650
K-6967	2750	346	112	48	160	186
K-6969	2810	313	92	56	149	164
K-7344	2870	176	68	31	98	78
K-7348	2990	360	72	69	140	219

IKU

T A B L E : V

CONCENTRATION OF EOM AND CHROMATOGRAPHIC FRACTIONS

(mg/g TOC)

IKU-No	DEPTH (m)	EOM	Sat.	Aro.	HC	Non HC
K-6909	2300	48.3	21.3	9.8	31.1	17.2
K-6910	2315	50.3	14.4	11.7	26.1	24.2
K-6911	2330	54.4	14.8	13.0	27.8	26.6
K-6914	2375	50.4	14.3	10.5	24.9	25.5
K-6965	2690	32.3	3.7	2.5	6.2	26.0
K-6967	2750	43.3	14.0	6.0	20.0	23.3
K-6969	2810	39.1	11.5	7.1	18.6	20.5
K-7344	2870	25.1	9.7	4.4	14.0	11.1
K-7348	2990	44.9	9.0	8.6	17.6	27.4

IKU

T A B L E : VI

COMPOSITION IN % OF THE MATERIAL EXTRACTED FROM THE ROCK

IKU-No	DEPTH (m)	Sat --- EOM	Aro --- EOM	HC --- EOM	Sat --- Aro	Non HC ------ EOM	HC ------ Non HC
K-6909	2300	44.1	20.3	64.4	216.7	35.6	181.0
K-6910	2315	28.7	23.2	51.9	123.3	48.1	107.9
K-6911	2330	27.3	23.8	51.1	114.5	48.9	104.4
K-6914	2375	28.5	20.9	49.4	136.1	50.6	97.7
K-6965	2690	11.5	7.9	19.4	145.5	80.6	24.0
K-6967	2750	32.4	13.8	46.2	235.0	53.8	85.9
K-6969	2810	29.5	18.0	47.5	163.6	52.5	90.6
K-7344	2870	38.4	17.4	55.8	220.8	44.2	126.2
K-7348	2990	20.0	19.1	39.1	104.9	60.9	64.1

IKU

TABLE VII

TABULATION OF DATAS FROM THE GASCHROMATOGRAMS

IKU No.	DEPTH (m)	PRISTANE / n-C17	PRISTANE / PHYTANE	CPI
K6909	2300	1.2	1.8	1.0
K6910	2315	1.7	1.7	1.0
K6911	2330	1.7	1.9	1.0
K6914	2375	1.7	1.8	1.1
K6965	2690	2.2	6.3	1.3
K6967	2750	1.9	3.8	1.7
K6969	2810	1.6	3.5	1.7
K7344	2870	1.1	2.6	1.3
K7348	2990	.7	5.2	1.1

IKU

VITRINITE REFLECTANCE MEASUREMENTS

TABLE NO.: VIIIa

WELL NO.: 31/4-4

Sample	Depth metres	Vitrinite reflectance	Fluorescence in UV light	Exinite content
K 6902	1950	0.31(3)	Yellow-Orange	Trace
K 6905	2100	0.42(2)	Yellow-Orange	Trace
K 6906	2150	0.32(3)	Yellow-Orange	Trace
K 6909	2300	0.52(1)	Yellow	Moderate
K 6910	2315	0.50(9)	Yellow and Yellow-Orange	Low-Moderate
K 6911	2330	0.40(12)	Yellow and Yellow-Orange	Moderate
K 6914	2375	0.42(9)	Yellow and Yellow-Orange	Moderate
K 6957	2435	0.36(21)	Yellow-Orange	Low
K 6961	2570	0.40(20)	Yellow to Light Orange	Low
K 6963	2630	0.46(22)	Light Orange	Low
K 6965	2690	0.56(22)	Light Orange	Low
K 6967	2750	0.51(13)	Yellow-Orange and Mid-Orange	Low
K 6969	2810	0.44(18)	Light Orange	Moderate to Rich
K 7344	2870	0.54(13)	Yellow-Orange to Light Orange	Moderate to Rich
K 7346	2930	0.44(20)	Yellow-Orange to Light Orange	Rich
K 7348	2990	0.52(20)	Light and Mid-Orange	Low
K 7352	3110	0.60(21)	Light Orange	Moderate

IKU

VISUAL KEROGEN ANALYSIS

TABLE NO.: VIIIb

WELL NO.: 31/4-4

Sample	Depth	Composition of residue	Particle size	Preservation-palynomorphs	Thermal maturation index	Remarks
K 6909	2300	Cut,W,WC!,He,P,S/Am,Cy	F-M-L	poor	^{1}/1+	2300-2330 Strongly sapropelized terrestrial material, mainly cuticles from aggregates, embedding other palynodebris. Estimation of relative amounts of Am/He is difficult. Tasmanites is present, abundant in 2330. Pyrite framboids are abundant.
K 6910	2315	Cut,W,WC!,He,P,S/Am,Cy	F-M-L	poor	^{1}/1+	
K 6911	2330	Cut,W,WR!,He,P,S/Am,Cy	F-M-L	poor	^{1}/1+	
K 6912	2375	He,W,Cut,WR!,P,S/Am,Cy	F-M-L	poor	1+	Sapropelized cuticles as aggregate which also embed palynomorphs

ABBREVATIONS

Am	amorphous	Cy	cysts, algae	W	woody material	F	fine
He	herbaceous	P	pollen grains	C	coal	M	medium
Cut	cuticles	S	spores	R!	reworked	L	large

IKU

VISUAL KEROGEN ANALYSIS

TABLE NO.: VIIIb contd.

WELL NO.: 31/4-4

Sample	Depth	Composition of residue	Particle size	Preservation-palynomorphs	Thermal maturation index	Remarks
K 6965	2660	Am,Cy/He,Cut,W,WR!,P,S	F-M	poor to fair	1+ $^{1+}$/2-	Amorphous iron aggregates. Probably some caved material present.
K 6967	2720	Am,Cy/W,Cut,He,S,WR!,P	F-M-L	fair to good	$^{1+}$/2-	Dense aggregates. Spores abundant! Most indeterminated small fragments seen of woody nature! Aggregates may be derived from caved lithologies.
K 6969	2780	W,P,S,Cut,He,WR!,/Am, Cy	F-M-L	fair	1+ $^{1+}$/2-	Rich in pollen and spores. Pyrite framboids are abundant.

ABBREVATIONS

Am	amorphous	Cy	cysts, algae	W	woody material	F	fine
He	herbaceous	P	pollen grains	C	coal	M	medium
Cut	cuticles	S	spores	R!	reworked	L	large

IKU

VISUAL KEROGEN ANALYSIS

TABLE NO.: VIIIb contd.

WELL NO.: 31/4-4

Sample	Depth	Composition of residue	Particle size	Preservation-palynomorphs	Thermal maturation index	Remarks
K 7344	2840	He,W,P,S,Cut,WR!,/Am, Cy	F-M	fair	$2^-/2$	Fusinite/structured wood matter. Late Jurassic cysts are abundant and indicate presence of much caved amorphous material in this sample. Probably lithology poor in indigenous organic matter.
K 7348	2960	Am,Cy/Cut,He,W,P,S,WR!	F-M-L	good to fair	1^+ 2^-	Aggregates include true sapropel and sapropelized cuticles, proportions are difficult to evaluate.

ABBREVATIONS

Am	amorphous	Cy	cysts, algae	W	woody material	F	fine
He	herbaceous	P	pollen grains	C	coal	M	medium
Cut	cuticles	S	spores	R!	reworked	L	large

IKU

TABLE IX

ROCK EVAL PYROLYSES

IKU No.	DEPTH (m)	S1	S2	S3	TOC (%)	HYDR. INDEX	OXYGEN INDEX	OIL OF GAS CONTENT S1+S2	PROD. INDEX S1/(S1+S2)	TEMP. max (C)
K6909	2300	.61	2.03	2.43	1.30	156	187	2.64	.23	424
K6910	2315	.98	27.53	.86	5.40	510	16	28.51	.03	424
K6911	2330	1.46	40.43	.82	6.56	616	12	41.89	.03	423
K6914	2375	1.33	27.86	1.00	5.33	523	19	29.19	.05	423
K6965	2640	2.91	50.72	1.21	31.50	161	4	53.63	.05	435
K6967	2730	.48	9.76	.74	5.46	179	14	10.24	.05	438
K6969	2810	.49	4.41	.82	1.64	269	50	4.90	.10	435
K7344	2870	.33	2.05	1.22	1.14	180	107	2.38	.14	421
K7348	2990	.50	3.33	.86	1.68	198	51	3.83	.13	438