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GEOCHEMICAL EVALUATION OF POTENTIAL DRILLING MUD CONTAMINATION OF GEOLOGICAL SAMPLES FROM THE NORSK HYDRO 7228/9-1 WELL, BARENTS SEA

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1 SUMMARY

A geochemical evaluation of a potential contamination problem has been carried out on samples from, and additives employed during the drilling of, the Norsk Hydro 7228/9-1 well, and the results are presented in this final report.

Analytical data derived from ten organic based additives and selected geological samples, coupled with previously generated data, have been used to evaluate the likelihood that the water-based drilling fluid employed during the drilling of this well has contaminated the ditch cuttings and sidewall core samples.

The reasons why a water-based drilling fluid has caused such problems are uncertain, but it appears very likely that the high overpressure of mud employed during the drilling programme is a contributing factor.

It is noted that the precision of the data derived from the additives is somewhat poor.

It should be remembered that the methods of analysis employed are specifically designed for geological samples with natural chemical properties and not man-made additives.

2 INTRODUCTION

A geochemical evaluation of mud samples, ditch cuttings samples and sidewall cores from the Norsk Hydro 7228/9-1 well has been undertaken, along with several mud additives used during the drilling of the well. The objectives of the project were concerned with the identification of any effects that drilling mud/additives might have had upon gas chromatography data obtained from geological samples from this well. The investigative programme was chiefly aimed at determining the possible origin of a distinct unresolved envelope of naphthenic compounds and a strong concentration of branched cyclic alkanes, as opposed to straight chain alkanes.

PROJECT DETAILS

The analytical and interpretative programme undertaken for this study was conducted in two phases.

Phase 1 Details

The first phase of this work, forming the major part of the study, was undertaken following the outline in The Robertson Group Proposal No. 91/Ic/020, and forwarded to J Augustson of Norsk Hydro on 10 April 1991.

Samples were received in two batches as detailed below:

Consignment	Sample Type	Number of Samples	Date of Receipt
1	Additives	10	1 May 1991
2	Canned muds	7	8 May 1991
	Wet cuttings	8	
	Bottled sidewall cores	6 (1 empty)	

As outlined above the samples were analysed with the express aim of determining the presence or otherwise of contamination in the geological samples. The additives were analysed for organic carbon content, Rock-Eval pyrolysis properties and extractability. The extracts from the samples were further analysed by fractionation, with the whole extracts and saturate fractions being analysed by gas chromatography. The exceptions to this scheme were the three liquid additives, for which no TOC or pyrolysis analyses were attempted, with the liquids themselves being fractionated by column chromatography. A similar programme to the liquid additives was employed for the mud samples. A selected number of the cuttings and sidewall core samples were analysed for pyrolysis

properties, with a full data set of extraction and fractionation data being obtained. Selected samples were analysed by saturate fraction gas chromatography. Analytical procedures and techniques are presented in Appendix 2 of this report.

The numbers of analyses carried out during Phase 1 of this study are as follows:

Sample preparation and description	:	14
Total carbon content	:	7
Rock-Eval pyrolysis	:	16
Quantitative extraction	:	21
Non-quantitative extraction	:	10
Iatroscan fractionation	:	31
Column chromatography	:	4
Whole extract gas chromatography	:	17
Saturate fraction gas chromatography	:	28

Data were sent to the client by facsimile, on three separate occasions, as the study progressed. Whole extract chromatograms of the muds and additives were forwarded on 31 May 1991 (Fax. ref. 3860). This was followed on 7 June (Fax. ref. 4028) by the majority of the saturate fraction gas chromatograms. The final facsimile on 11 June (Fax. ref. 4088/91) contained all the tabulated data and several outstanding saturate fraction gas chromatograms, as well as the interim interpretation. A proof copy of the report for Phase 1 of the study was forwarded to the client on 21 June.

Phase 2 Details

Following the client's review of the data in the proof report, it was decided that further studies were required. This smaller phase of analyses, concentrating entirely on the mud additives, was undertaken in order to try and gather information on the effects of altering the concentration of additives to solvent, and the resulting effects on the weight of extract obtained and the subsequent fractionation and gas chromatographic analyses.

Following telephone discussions with J Augustson of Norsk Hydro an outline and costing of the work programme was forwarded via facsimile on 28 June 1991, and agreed to on 3 July. During the progress of this phase of the study numerous discussions of the data were undertaken with the client and further analyses were added into the work programme, namely the extraction of additives in the presence of sand and fullers earth bases in order to study possible matrix effects on the amounts and nature of the extracts obtained.

The numbers of analyses carried out during this phase of the study are as follows:

Quantitative extraction of pure additives (varying weights)	:	33
Iatroscan fractionation of pure additive extracts	:	24
Saturate fraction gas chromatography of pure additive	:	10
Quantitative extraction of additive/sand mixtures	:	15
Iatroscan fractionation of additive/sand extracts	:	6
Saturate fraction gas chromatography of additive/sand mixtures	:	2
Quantitative extraction of additive/fullers earth mixtures	:	4
Iatroscan fractionation of additive/fullers earth extracts	:	4
Saturate fraction gas chromatography of additive/fullers earth mixtures	:	1

Initial data from this phase of the study were forwarded to the client on 22 July 1991 (Fax. ref. 4933). A follow up data package was sent on 3 September (Fax. ref. 6137).

The Robertson Group personnel involved in this study were as follows:

Project advice and data interpretation	:	C Darlington
Project co-ordination, data interpretation and report preparation	:	I Cutler
Chemical analyses	:	supervised by M Wadsworth

PHASE 1

4.2 PRODEFOAM

Product Details

Full product name : PRODEFOAM
Supplier : Anchor Drilling Fluids/Promud

Description and Composition

Known composition : Low aromatic mineral oil (60-100 wt.%)
Fatty acid amid (1-5 wt.%)
Polyglycol ether (1-5 wt.%)
Polymetacrylate (0-1 wt.%)
Fatty acid ether (1-5 wt.%)
Physical description : Light brown, viscous liquid
Known properties : Spec. Grav. 0.91-0.93
Boiling point 230°C-260°C

Product Functions

Primary product function : Defoaming agent
Secondary product functions : -
Recommended mud systems : Water base fluids

4.3 **PROLUBE**

Product Details

Full product name : **PROLUBE**
Supplier : **Anchor Drilling Fluids/Promud**

Description and Composition

Known composition : **Vegetable fatty acid ester**
 : **Ester - Alcohol**
 : **Emulsifier**
Physical description : **Light yellow oily liquid; smells like**
 : **vegetable oil**
Known properties : **Spec. Grav. 0.96**

Product Functions

Primary product functions : **Lubricant**
Secondary product functions : **Pipe freeing agent, surfactant**
Recommended mud systems : **Water base fluids**

4.4 PROBIO 2

Product Details

Full product name : PROBIO 2
Supplier : Anchor Drilling Fluids/Promud

Description and Composition

Known composition : Glutaraldehyde (25 wt.%)
Water (75 wt.%)
Physical description : Slightly yellow liquid; odourless
Known properties : Spec. Grav. 1.05
Boiling point >100°C
pH in soln. 3.5

Product Functions

Primary product function : Bactericide
Secondary product functions : -
Recommended mud systems : Water base fluids

4.5 **PROPOL REG**

Product Details

Full product name : **PROPOL REG**
Supplier : **Anchor Drilling Fluids/Promud**

Description and Composition

Known composition : **Polyanionic cellulosic polymer (100 wt.%)**
Physical description : **Dry, cream-coloured powder; odourless**
Known properties : **Spec. Grav. 1.6**
 : **pH in soln. 8.5-9.5**

Product Functions

Primary product function : **Viscosifier**
Secondary product functions : **Shale control agent**
Recommended mud systems : **Water base fluids, air/mist/foam/gas systems**

4.6 XANTHAN POLYMER

Product Details

Full product name : XANTHAN POLYMER
Supplier : Anchor Drilling Fluids/Promud

Description and Composition

Known composition : Xanthan gum (water soluble polysaccharide)
Physical description : Cream-coloured powder; odourless;
soluble in water
Known properties : Spec. Grav. 1.0-1.2
pH in soln. 7.0

Product Functions

Primary product function : Viscosifier
Secondary product functions : -
Recommended mud systems : Water base fluids, air/mist/foam/gas
systems

4.7 PROCAP

Product Details

Full product name : PROCAP
Supplier : Anchor Drilling Fluids/Promud

Description and Composition

Known composition : Partially hydrolised polyacrylamide
(30 wt.%)
Potassium chloride (70 wt.%)
Physical description : Yellow-white powder
Known properties : Spec. Grav. 0.95-1.04

Product Functions

Primary product function : Shale control agent
Secondary product functions : Viscosifier, filtration reducer
Recommended mud systems : Water base fluids

4.8 PAC POLYMER REG

Product Details

Full product name : PAC POLYMER REG
Supplier : Anchor Drilling Fluids/Promud

Description and Composition

Known composition : Polyanionic cellulosic polymer (100 wt.%)
Physical description : Dry, cream-coloured powder; odourless
Known properties : Spec. Grav. 1.6
pH in soln. 8.5-9.5

Product Functions

Primary product functions : Viscosifier
Secondary product functions : Shale control agent, emulsifier
Recommended mud systems : Water base fluids, air/mist/foam/gas systems

4.9 THERMOPOL

Product Details

Full product name : THERMOPOL
Supplier : Anchor Drilling Fluids/Promud

Description and Composition

Known composition : Synthetic copolymer
Physical description : White powder; odourless
Known properties : Spec. Grav. 1.3

Product Functions

Primary product functions : Filtration reducer
Secondary product functions : Thinner/dispersant, shale control agent
Recommended mud systems : Water base fluids

4.10 PAC POLYMER S

Product Details

Full product name : PAC POLYMER S
Supplier : Anchor Drilling Fluids/Promud

Description and Composition

Known composition : Polyanionic cellulosic polymer (100 wt.%)
Physical description : Dry, cream-coloured powder; odourless
Known properties : Spec. Grav. 1.6
pH in soln. 8.5-9.5

Product Functions

Primary product function : Viscosifier
Secondary product functions : Shale control agent, emulsifier
Recommended mud systems : Water base fluids, air/mist/foam/gas systems

4.11 PAC POLYMER SL

Product Details

Full product name : PAC POLYMER SL
Supplier : Anchor Drilling Fluids/Promud

Description and Composition

Known composition : Polyanionic cellulosic polymer (100 wt.%)
Physical description : Dry, cream-coloured powder; odourless
Known properties : Spec. Grav. 1.6
pH in soln. 8.5-9.5

Product Functions

Primary product functions : Viscosifier
Secondary product functions : Shale control agent, emulsifier
Recommended mud systems : Water base fluids, air/mist/foam/gas systems

MASS OF ADDITIVE USED IN EACH DRILL HOLE, kg				
17 1/2"	12 1/4"	8 1/4"	PLUG	HOLE SIZE
948-2600m	2600-4176m	4176-4600m	4600m	DEPTH RANGE

ADDITIVE NAME					TOTAL MASS OF ADDITIVE USED
PRODEFOAM	-	38	75	-	113
PROLUBE	-	4164	-	-	4164
PROBIO 2 *	725l	725l	-	100l	1550l
PROPOL REG	-	-	200	-	200
XANTHAN POLYMER	675	-	-	-	675
PROCAP	8650	6650	775	-	16075
PAC POLYMER REG	11800	4975	8750	-	25525
THERMOPOL	-	5064	1563	-	6627
PAC POLYMER S	825	4525	350	-	5700
PAC POLYMER SL	-	675	-	-	675
ORGANIC ADDITIVES ANALYSED DURING THIS STUDY					
WALLNUT	-	-	100	-	100
ORGANIC ADDITIVES NOT ANALYSED DURING THIS STUDY					
BARITE	152000	86000	33000	-	271000
BENTONITE	3000	-	-	-	3000
CAUSTIC SODA	800	1525	775	-	3100
POTASSIUM BRINE	365000	273000	-	-	638000
POTASSIUM CL	1250	2500	5000	-	8750
SODA ASH	1675	575	600	-	2850
SODIUM BICARB	-	1750	1575	-	3325
SODIUM CHLORIDE	-	-	80000	-	80000
INORGANIC ADDITIVES					

KEY

* - The amounts of PROBIO 2 are given as a volume, in litres.

ADDITIVE USAGE DURING EACH STAGE OF DRILLING
TABLE: 1

GENERAL DATA			CHEMICAL ANALYSIS DATA											
SAMPLE CODE	SAMPLE TYPE	ANALYSED LITHOLOGY	TOTAL CARBON % OF SAMPLE	PYROLYSIS					SOLVENT EXTRACTION/FRACTIONATION					
				Tmax °C	HI	OI	PI	POT.YLD. (ppm)	EXTR. (ppm)	HC (ppm)	EXTR. % OC	HC		ALK. % HC
				% OC	% EX									
PRODEFOAM	Add	Not applicable	-						*	-	-	-	52	75
PROLUBE	Add	Not applicable	-						*	-	-	-	*	*
PROBIO 2	Add	Not applicable	-						*	-	-	-	*	*
PROPOL REG	Add	Not applicable	32.5	421	121	264	0.43	39460	310	15	0.1	0.0	5	87
XANTHAN POLYMER	Add	Not applicable	34.5	421	70	244	0.68	24160	620	89	0.2	0.9	14	70
PROCAP	Add	Not applicable	10.1	398	347	116	0.06	35040	1255	35	1.2	0.3	3	63
PAC POLYMER REG	Add	Not applicable	32.0	419	111	268	0.45	35510	290	10	0.1	0.0	3	79
THERMOPOL	Add	Not applicable	31.3	401	102	185	0.81	31800	770	50	0.2	0.2	6	66
PAC POLYMER S	Add	Not applicable	27.7	401	110	283	0.38	30560	9615	*	3.5	*	*	*
PAC POLYMER SL	Add	Not applicable	26.5	404	135	293	0.36	35730	3215	770	1.2	2.9	24	17
1010.0m	Mud	Not applicable	-						*	-	-	-	31	86
1010m	Ctgs	MDST, med gy+ 10% MDST, gy-red+ mnr SST, ol-gy	-						150	100	-	-	67	89
1077.0m	Mud	Not applicable	-						*	-	-	-	18	67
1077m	Ctgs	MDST, brn-blk, slty+ 10% MDST, lt gy, sndy+ mnr LST, v lt gy+ mnr SST, ol-gy	-	413	*	*	0.06	28980	3525	1440	-	-	41	20
1138.0m	Swc	SST, v pal orng+ 10% SND, crs	-	415	*	*	0.86	760	8365	7095	-	-	85	70
1537.5m	Swc	LST, lt gy	-						100	75	-	-	75	78
1540.0m	Mud	Not applicable	-						*	-	-	-	37	92
1540m	Ctgs	MDST, dk gy, slty+ 30% MDST, lt gy+ mnr SH, gy-blk+ tr MDST, v dsk red	-						75	45	-	-	60	72
2493.0m	Swc	MDST, med-lt gy, shly	-	*	*	*	1.00	*	200	125	-	-	63	75
2500.0m	Mud	Not applicable	-						*	-	-	-	31	88
2500m	Ctgs	MDST, med-lt gy+ 30% SH, med-dk gy	-	*	*	*	0.50	20	125	60	-	-	48	81
3500.0m	Mud	Not applicable	-						*	-	-	-	1	71
3500m	Ctgs	MDST, med gy+ 20% SH, med-dk gy	-						65	35	-	-	54	90
3577.0m	Swc	No sample	-											
3932.0m	Swc	MDST, brn-blk, carb+ mnr SND	-	*	*	*	0.70	1180	1250	580	-	-	46	98

SUMMARY OF CHEMICAL ANALYSIS DATA
TABLE: 2A

GENERAL DATA			CHEMICAL ANALYSIS DATA											
SAMPLE CODE	SAMPLE TYPE	ANALYSED LITHOLOGY	TOTAL CARBON % OF SAMPLE	PYROLYSIS					SOLVENT EXTRACTION/FRACTIONATION					
				Tmax °C	HI	OI	PI	POT. YLD. (ppm)	EXTR. (ppm)	HC (ppm)	EXTR. % OC	HC		ALK. % HC
												% OC	% EX	
3932m, Mld Wash	Ctgs	SH, blk, carb+ mnr MDST, med-dk gy, slty+ mnr SST, lt gy+ tr LST, v lt gy	-	*	*	*	0.38	840	500	220	-	-	44	87
3932m, Stg Wash	P	SH, blk, carb+ mnr MDST, med-dk gy, slty+ mnr SST, lt gy+ tr LST, v lt gy	-	*	*	*	0.33	180	140	70	-	-	50	87
4000.0m	Mud	Not applicable	-						*	-	-	-	6	91
4292.0m	Swc	SH, ol-gy, calc	-	*	*	*	0.61	110	320	205	-	-	64	99
4292m	Ctgs	LST, lt gy+ 40% SH, dk gy, calc	-	*	*	*	0.18	90	90	40	-	-	44	97
4500.0m	Mud	Not applicable	-						*	-	-	-	27	99
4500m	Ctgs	ANH+ 30% SH, v lt gy+ 10% LST, dk gy+ mnr SND	-						135	85	-	-	63	68

SUMMARY OF CHEMICAL ANALYSIS DATA
TABLE: 2B

GENERAL DATA			CHEMICAL ANALYSIS DATA									
SAMPLE CODE	SAMPLE TYPE	ANALYSED LITHOLOGY	TOTAL CARBON % OF SAMPLE	ROCK-EVAL PYROLYSIS DATA								
				Tmax °C	S1 (ppm)	S2 (ppm)	S3 (ppm)	HI	OI	PI	S2/S3	S1+S2
PROPOL REG	Add	Not applicable	32.5	421	29170	39460	85850	121	264	0.43	0.46	68630
XANTHAN POLYMER	Add	Not applicable	34.5	421	50570	24160	84210	70	244	0.68	0.29	74730
PROCAP	Add	Not applicable	10.1	398	2250	35040	11760	347	116	0.06	2.98	37290
PAC POLYMER REG	Add	Not applicable	32.0	419	29210	35510	85850	111	268	0.45	0.41	64720
THERMOPOL	Add	Not applicable	31.3	401	138240	31800	57750	102	185	0.81	0.55	170040
PAC POLYMER S	Add	Not applicable	27.7	401	18860	30560	78490	110	283	0.38	0.39	49420
PAC POLYMER SL	Add	Not applicable	26.5	404	20000	35730	77640	135	293	0.36	0.46	55730
1077m	Ctgs	MDST, brn-blk, slty+ 10% MDST, lt gy, sndy+ mnr LST, v lt gy+ mnr SST, ol-gy	-	413	1970	28980	810	*	*	0.06	35.78	30950
1138.0m	Swc	SST, v pal orng+ 10% SND, crs	-	415	4760	760	460	*	*	0.86	1.65	5520
2493.0m	Swc	MDST, med-lt gy, shly	-	*	40	*	460	*	*	1.00	0.00	40
2500m	Ctgs	MDST, med-lt gy+ 30% SH, med-dk gy	-	*	20	20	770	*	*	0.50	0.03	40
3932.0m	Swc	MDST, brn-blk, carb+ mnr SND	-	*	2720	1180	1090	*	*	0.70	1.08	3900
3932m, Mld Wash	Ctgs	SH, blk, carb+ mnr MDST, med-dk gy, slty+ mnr SST, lt gy+ tr LST, v lt gy	-	*	510	840	950	*	*	0.38	0.88	1350
3932m Stg Wash	P	SH, blk, carb+ mnr MDST, med-dk gy, slty+ mnr SST, lt gy+ tr LST, v lt gy	-	*	90	180	590	*	*	0.33	0.31	270
4292.0m	Swc	SH, ol-gy, calc	-	*	170	110	1060	*	*	0.61	0.10	280
4292m	Ctgs	LST, lt gy+ 40% SH, dk gy, calc	-	*	20	90	570	*	*	0.18	0.16	110

KEY

S1 = Free Hydrocarbons	HI = Hydrogen Index	S2/S3 = Quality Index
S2 = Potential Yield	OI = Oxygen Index	S1+S2 = Genetic Potential
S3 = Carbon Dioxide	PI = Production Index	

NB: The hydrogen and oxygen indices are calculated using the total carbon percentage on the assumption that this is equal to the total organic carbon content for these samples.

ORGANIC CARBON AND ROCK-EVAL PYROLYSIS DATA
TABLE: 3

GENERAL DATA			SOLVENT EXTRACTION AND IATROSCAN DATA								
SAMPLE CODE	SAMPLE TYPE	ANALYSED LITHOLOGY	SAMPLE WEIGHT g	EXTR. WEIGHT mg	EXTR. ppm	ALKS. % OF EXTR.	AROMS. % OF EXTR.	POLARS % OF EXTR.	HYDROCARBONS		ALKS. % OF HC
									ppm	% OF EXTR.	
PRODEFOAM	Add	Not applicable	*	*	*	39	13	48	*	52	75
PROLUBE	Add	Not applicable	*	*	*	*	*	*	*	*	*
PROBIO 2	Add	Not applicable	*	*	*	*	*	*	*	*	*
PROPOL REG	Add	Not applicable	10.0	3.1	310	4.2	0.6	95.2	15	5	87
XANTHAN POLYMER	Add	Not applicable	10.0	6.2	620	10.0	4.3	85.6	89	14	70
PROCAP	Add	Not applicable	15.0	18.8	1255	1.8	1.0	97.2	35	3	63
PAC POLYMER REG	Add	Not applicable	10.0	2.9	290	2.7	0.7	96.6	10	3	79
THERMOPOL	Add	Not applicable	10.0	7.7	770	4.3	2.2	93.5	50	6	66
PAC POLYMER S	Add	Not applicable	12.0	115.4	9615	*	*	100.0	*	*	*
PAC POLYMER SL	Add	Not applicable	12.0	38.6	3215	4.1	19.9	76.0	770	24	17
1010.0m	Mud	Not applicable	*	*	*	26.7	4.3	69.0	*	31	86
1010m	Ctgs	MDST, med gy+ 10% MDST, gy-red+ mnr SST, ol-gy	8.0	1.2	150	59.3	7.3	33.3	100	67	89
1077.0m	Mud	Not applicable	*	*	*	12.1	5.9	82.0	*	18	67
1077m	Ctgs	MDST, brn-blk, slty+ 10% MDST, lt gy, sndy+ mnr LST, v lt gy+ mnr SST, ol-gy	8.0	28.2	3525	8.2	32.7	59.1	1440	41	20
1138.0m	Swc	SST, v pal orng+ 10% SND, crs	6.0	50.2	8365	59.4	25.4	15.2	7095	85	70
1537.5m	Swc	LST, lt gy	8.0	0.8	100	58.5	16.5	25.0	75	75	78
1540.0m	Mud	Not applicable	*	*	*	34.0	3.0	63.0	*	37	92
1540m	Ctgs	MDST, dk gy, slty+ 30% MDST, lt gy+ mnr SH, gy-blk+ tr MDST, v dsk red	8.0	0.6	75	43.2	16.8	40.0	45	60	72
2493.0m	Swc	MDST, med-lt gy, shly	2.0	0.4	200	46.9	15.6	37.5	125	63	75
2500.0m	Mud	Not applicable	*	*	*	27.3	3.7	69.0	*	31	88
2500m	Ctgs	MDST, med-lt gy+ 30% SH, med-dk gy	8.0	1.0	125	38.9	9.1	52.0	60	48	81
3500.0m	Mud	Not applicable	*	*	*	0.7	0.3	99.0	*	1	71
3500m	Ctgs	MDST, med gy+ 20% SH, med-dk gy	11.0	0.7	65	48.5	5.4	46.2	35	54	90
3577.0m	Swc	No sample	-	-	-	-	-	-	-	-	-
3932.0m	Swc	MDST, brn-blk, carb+ mnr SND	0.8	1.0	1250	45.5	0.9	53.6	580	46	98

SOLVENT EXTRACTION AND IATROSCAN FRACTIONATION DATA
TABLE: 4A

GENERAL DATA			SOLVENT EXTRACTION AND IATROSCAN DATA								
SAMPLE CODE	SAMPLE TYPE	ANALYSED LITHOLOGY	SAMPLE WEIGHT g	EXTR. WEIGHT mg	EXTR. ppm	ALKS. % OF EXTR.	AROMS. % OF EXTR.	POLARS % OF EXTR.	HYDROCARBONS		ALKS. % OF HC
									ppm	% OF EXTR.	
3932m, Mld Wash	Ctgs	SH, blk, carb+ mnr MDST, med-dk gy, slty+ mnr SST, lt gy+ tr LST, v lt gy	5.0	2.5	500	38.3	5.7	56.0	220	44	87
3932m, Stg Wash	P	SH, blk, carb+ mnr MDST, med-dk gy, slty+ mnr SST, lt gy+ tr LST, v lt gy	10.0	1.4	140	43.5	6.5	50.0	70	50	87
4000.0m	Mud	Not applicable	*	*	*	5.5	0.5	94.0	*	6	91
4292.0m	Swc	SH, ol-gy, calc	5.0	1.6	320	63.4	0.6	35.9	205	64	99
4292m	Ctgs	LST, lt gy+ 40% SH, dk gy, calc	12.0	1.1	90	43.1	1.3	55.6	40	44	97
4500.0m	Mud	Not applicable	*	*	*	26.7	0.3	73.0	*	27	99
4500m	Ctgs	ANH+ 30% SH, v lt gy+	12.0	1.6	135	42.8	20.1	37.0	85	63	68

SOLVENT EXTRACTION AND IATROSCAN FRACTIONATION DATA
TABLE: 4B

GENERAL DATA		SOLVENT EXTRACTION AND COLUMN CHROMATOGRAPHY DATA												
SAMPLE CODE	SAMPLE TYPE	SAMPLE WEIGHT g	EXTR. WEIGHT mg	EXTR. ppm	COLUMN CHROMATOGRAPHY DATA				NORMALISED COLUMN CHROMATOGRAPHY DATA			HYDROCARBONS		ALKS % OF HC
					ALKS % OF EXTR.	AROMS % OF EXTR.	POLARS % OF EXTR.	TOTAL RECOV. %	ALKS %	AROMS %	POLARS %	ppm	% OF EXTR.	
PRODEFOAM	Add	*	*	*	23.1	3.6	14.0	40.7	56.8	8.8	34.4	*	26.7	86.5
PROLUBE	Add	*	*	*	0.6	48.1	31.1	79.8	0.8	60.3	39.0	*	48.7	1.2
PROBIO 2	Add	*	*	*	0.3	1.8	0.8	2.9	10.3	62.1	27.6	*	2.1	14.3
3500.0m	Mud	*	*	*	2.8	1.7	27.1	31.6	8.9	5.4	85.8	*	4.5	62.2

COLUMN CHROMATOGRAPHY DATA
TABLE: 5

SAMPLE DATA						
SAMPLE CODE SAMPLE TYPE	PRODEFOAM Add	PROLUBE Add	PROBIO 2 Add	PROPOL REG Add	XANTHAN POLYMER Add	PROCAP Add

COMPONENTS	QUANTIFIED NORMAL AND ISOPRENOID ALKANE ABUNDANCES (%)					
n-C10						
n-C11						
n-C12	0.21		0.44			
n-C13	2.09	0.61				
n-C14	5.40	1.73				
n-C15	7.68	2.84	0.44	0.73	0.53	4.87
n-C16	9.26	3.55	1.51	0.75	1.00	9.92
n-C17	9.73	3.92	2.04	1.56	2.05	5.15
n-C18	8.89	4.01	2.33	4.27	4.58	5.50
n-C19	7.92	3.19	2.17	3.10	3.87	4.60
n-C20	7.24	4.83	3.25	6.48	8.17	5.10
n-C21	6.14	3.41	3.51	5.38	5.81	4.49
n-C22	4.55	3.74	5.08	9.81	6.68	5.12
n-C23	3.05	2.50	4.82	5.18	6.59	4.68
n-C24	2.31	3.18	3.70	4.09	8.14	3.85
n-C25	1.30	6.37	27.20	5.38	3.96	4.17
n-C26	0.50	2.77	5.14	3.00	3.79	3.88
n-C27	0.16	3.48	3.70	5.79	6.01	3.14
n-C28	0.11	7.12	4.26	3.57	5.01	2.77
n-C29	0.05	7.06	4.13	9.41	6.85	4.83
n-C30	0.03	2.08	4.07	2.29	2.81	2.05
n-C31	0.02	17.62	4.34	12.60	6.06	4.89
n-C32	0.01	1.66	2.49	1.62	1.11	3.28
n-C33	0.01	2.88	2.22	5.59	3.89	4.07
n-C34	0.01	0.64	2.05	2.01	2.84	2.35
n-C35	0.02	0.66	1.74	2.27	2.56	3.07
n-C36		0.18	0.89	0.52	0.01	0.40
i-C15 (Farnesane)	2.15	0.75	0.21			
i-C16	3.41	1.25	0.69	0.23		0.45
i-C18 (Norpristane)	4.69	1.55	1.78	0.38	0.63	1.36
i-C19 (Pristane)	7.59	3.62	2.84	1.18	2.96	3.00
i-C20 (Phytane)	5.45	2.83	2.95	2.80	4.08	3.02

GENERAL DATA						
Total Abundance (%)	100	100	100	100	100	100
TOC (% of rock)	*	*	*	10.0	10.0	15.0
Sample Weight (g)	*	*	*	3.1	6.2	18.8
Extract Weight (mg)	*	*	*	310	620	1255
Extract (ppm)	*	*	*	15	89	35
Hydrocarbons (ppm)	52	*	*	5	14	3
Hydrocarbons (% extr)	75	*	*	87	70	63
Alks (% hydrocarbons)						

RATIOS						
CPI-1	1.43	2.42	2.21	2.88	1.50	1.40
CPI-2	1.44	2.41	2.38	2.86	1.48	1.39
CPI-3	0.52	0.70	0.79	1.76	1.37	0.94
Bias	4.12	0.47	0.30	0.54	0.59	0.96
i-C19 / n-C17	0.78	0.92	1.39	0.76	1.44	0.58
i-C20 / n-C18	0.61	0.71	1.27	0.66	0.89	0.55
i-C19 / i-C20	1.39	1.28	0.96	0.42	0.73	0.99

LEGEND	
i - isoprenoid	n - normal
For definition of Ratios CPI-1,-2,-3 and Bias - see following page	

ALKANE GAS CHROMATOGRAPHY DATA

SAMPLE DATA						
SAMPLE CODE	PAC POLYMER REG	THERMOPOL	PAC POLYMER S	1077.0m	1077m	1138.0m
SAMPLE TYPE	Add	Add	Add	Mud	Ctgs	Swc

COMPONENTS	QUANTIFIED NORMAL AND ISOPRENOID ALKANE ABUNDANCES (%)					
n-C10						0.18
n-C11						0.68
n-C12						2.05
n-C13						4.38
n-C14	0.39			0.34		10.21
n-C15	1.21			1.32		9.98
n-C16	1.69		0.93	4.63		9.41
n-C17	2.01	0.88	1.72	4.76	6.59	7.78
n-C18	3.72	6.05	2.67	4.41	5.52	6.31
n-C19	3.25	6.13	3.10	4.60	4.76	4.11
n-C20	7.00	8.17	4.60	5.81	3.91	3.92
n-C21	4.96	6.31	5.85	4.56	3.47	3.44
n-C22	9.42	12.31	6.79	5.48	2.75	2.02
n-C23	4.94	5.72	5.60	5.44	2.93	2.68
n-C24	5.05	3.88	4.87	6.52	2.38	3.06
n-C25	6.27	9.48	5.97	6.89	2.53	1.90
n-C26	2.82	2.67	4.16	7.41	3.37	2.12
n-C27	4.39	4.46	7.21	5.40	2.06	1.57
n-C28	2.31	2.85	8.60	6.36	2.20	1.53
n-C29	8.39	6.84	9.82	4.60	2.72	1.03
n-C30	2.28	1.86	2.74	3.70	1.50	0.45
n-C31	11.67	6.41	10.57	3.09	1.77	1.26
n-C32	1.44	0.89	2.25	2.49	0.79	1.10
n-C33	5.74	2.85	5.15	2.30	1.66	0.87
n-C34	1.82	1.79	1.08	1.72	1.96	0.27
n-C35	2.87	1.09	2.39	3.14	3.18	0.11
n-C36	1.01	0.35	0.66	0.61	0.21	1.22
i-C15 (Farnesane)					0.36	5.70
i-C16	0.36	0.17		0.26	1.53	7.52
i-C18 (Norpristane)	0.47	0.78	0.30	0.89	4.61	5.63
i-C19 (Pristane)	2.09	2.94	1.29	4.10	17.23	
i-C20 (Phytane)	2.43	5.14	1.69	3.75	12.73	

GENERAL DATA						
Total Abundance (%)	100	100	100	100	100	100
TOC (% of rock)	10.0	10.0	12.0	*	8.0	6.0
Sample Weight (g)	2.9	7.7	115.4	*	28.2	50.2
Extract Weight (mg)	290	770	9615	*	3525	8365
Extract (ppm)	10	50	*	*	1440	7095
Hydrocarbons (ppm)	3	6	*	18	41	85
Hydrocarbons (% extr)	79	66	*	67	20	70
Alks (% hydrocarbons)						

RATIOS						
CPI-1	3.02	2.73	1.88	0.93	1.07	0.97
CPI-2	2.97	2.85	1.77	0.92	1.06	0.91
CPI-3	1.71	1.62	1.13	0.78	0.74	0.73
Bias	0.58	0.83	0.38	0.57	1.31	2.46
i-C19 / n-C17	1.04	3.34	0.75	0.89	2.62	0.75
i-C20 / n-C18	0.65	0.85	0.63	0.79	2.31	0.60
i-C19 / i-C20	0.86	0.57	0.76	1.09	1.35	1.34

LEGEND	
i - isoprenoid	n - normal
For definition of Ratios CPI-1,-2,-3 and Bias - see following page	

ALKANE GAS CHROMATOGRAPHY DATA

TABLE: 6B

SAMPLE DATA						
SAMPLE CODE	1537.5m	1540.0m	1540m	2493.0m	2500.0m	2500m
SAMPLE TYPE	Swc	Mud	Ctgs	Swc	Mud	Ctgs

COMPONENTS	QUANTIFIED NORMAL AND ISOPRENOID ALKANE ABUNDANCES (%)					
	1537.5m Swc	1540.0m Mud	1540m Ctgs	2493.0m Swc	2500.0m Mud	2500m Ctgs
n-C10						
n-C11						
n-C12						
n-C13						
n-C14		0.28				
n-C15	0.25	1.28	0.11		0.31	
n-C16	1.08	2.61	0.19	0.31	0.66	
n-C17	5.17	4.75	1.26	1.50	1.89	1.53
n-C18	9.37	4.82	3.67	5.81	2.29	4.65
n-C19	8.88	5.51	6.56	9.97	3.21	8.63
n-C20	10.67	6.11	7.67	12.84	5.34	10.95
n-C21	7.63	5.42	8.01	9.28	6.32	9.21
n-C22	6.25	6.00	7.64	7.61	7.03	8.56
n-C23	6.51	7.71	7.89	5.05	7.71	8.36
n-C24	4.57	5.74	6.66	4.45	6.54	6.90
n-C25	4.14	8.27	7.94	4.96	8.03	6.69
n-C26	7.60	6.98	7.04	4.27	9.90	5.33
n-C27	3.13	4.59	7.05	4.84	6.41	4.23
n-C28	3.52	5.81	5.18	5.95	5.56	4.63
n-C29	2.13	3.65	6.11	4.18	4.42	3.96
n-C30	1.62	2.42	3.20	2.76	3.44	2.44
n-C31	1.31	1.77	4.38	2.21	3.47	2.54
n-C32	0.73	1.06	1.75	0.82	2.14	1.44
n-C33	1.19	1.38	2.13	1.64	2.64	1.99
n-C34	1.60	1.34	1.02	3.01	2.63	2.32
n-C35	1.74	2.11	1.34	2.46	4.55	1.56
n-C36	0.51	0.24	0.54		1.30	0.45
i-C15 (Farnesane)		0.07	0.03	0.10		
i-C16	0.13	0.44	0.06	0.26	0.25	
i-C18 (Norpristane)	0.95	1.46	0.14	0.56	0.45	
i-C19 (Pristane)	4.23	4.47	0.84	1.54	1.82	0.96
i-C20 (Phytane)	5.11	3.76	1.61	3.62	1.68	2.68

GENERAL DATA						
Total Abundance (%)	100	100	100	100	100	100
TOC (% of rock)	8.0	*	8.0	2.0	*	8.0
Sample Weight (g)	0.8	*	0.6	0.4	*	1.0
Extract Weight (mg)	100	*	75	200	*	125
Extract (ppm)	75	*	45	125	*	60
Hydrocarbons (ppm)	75	37	60	63	31	48
Hydrocarbons (% extr)	78	92	72	75	88	81
Alks (% hydrocarbons)						

RATIOS						
CPI-1	0.72	1.01	1.34	1.02	0.98	1.07
CPI-2	0.71	1.00	1.32	1.05	0.97	1.08
CPI-3	0.56	0.72	1.15	0.95	0.83	0.85
Bias	1.35	0.71	0.59	1.15	0.44	0.90
i-C19 / n-C17	0.82	0.94	0.67	1.03	0.96	0.63
i-C20 / n-C18	0.55	0.78	0.44	0.62	0.73	0.58
i-C19 / i-C20	0.83	1.19	0.52	0.43	1.08	0.36

LEGEND	
i - isoprenoid	n - normal
For definition of Ratios CPI-1,-2,-3 and Bias - see following page	

ALKANE GAS CHROMATOGRAPHY DATA

SAMPLE DATA						
SAMPLE CODE	3500.0m	3932.0m	3932m, Mld Wash	3932m, Stg Wash	4292.0m	4292m
SAMPLE TYPE	Mud	Swc	Ctgs	Ctgs (P)	Swc	Ctgs

COMPONENTS	QUANTIFIED NORMAL AND ISOPRENOID ALKANE ABUNDANCES (%)					
	3500.0m	3932.0m	3932m, Mld Wash	3932m, Stg Wash	4292.0m	4292m
n-C10						
n-C11						
n-C12						
n-C13						
n-C14				0.06		
n-C15	0.10		0.21	0.18		0.03
n-C16	0.46	0.62	1.47	0.51	1.30	0.28
n-C17	1.49	4.12	7.65	5.67	6.90	3.24
n-C18	2.72	7.66	9.57	12.83	8.69	6.68
n-C19	3.65	12.11	12.46	16.16	12.72	9.57
n-C20	4.98	13.95	11.46	12.61	11.68	10.55
n-C21	5.40	8.92	6.65	7.82	8.09	9.01
n-C22	5.35	7.60	5.05	6.09	5.44	9.47
n-C23	6.76	5.38	3.64	4.72	3.76	8.63
n-C24	7.66	4.00	2.34	3.51	3.33	7.09
n-C25	9.78	4.59	2.74	3.12	4.04	7.34
n-C26	14.20	3.45	2.54	2.81	3.51	5.69
n-C27	6.47	2.67	1.93	2.35	2.11	2.91
n-C28	7.12	4.36	4.27	2.93	5.03	3.45
n-C29	8.97	3.61	2.57	1.91	3.51	2.36
n-C30	3.07	1.67	1.29	1.14	2.02	1.62
n-C31	2.28	2.30	1.33	1.44	1.62	1.19
n-C32	1.45	1.26	1.21	0.79	0.22	0.72
n-C33	1.21	1.46	1.66	0.74	1.67	1.16
n-C34	1.86	1.38	1.79	0.91	2.22	0.99
n-C35	1.33	1.54	1.49	0.84	1.77	1.63
n-C36	0.23	0.43		0.21		0.44
i-C15 (Farnesane)						
i-C16	0.04		0.09	0.07		
i-C18 (Norpristane)	0.33	0.29	1.51	0.71	1.43	0.33
i-C19 (Pristane)	1.08	2.49	5.89	3.07	4.05	1.81
i-C20 (Phytane)	2.01	4.14	9.19	6.80	4.90	3.81

GENERAL DATA						
Total Abundance (%)	100	100	100	100	100	100
TOC (% of rock)	*	0.8	5.0	10.0	5.0	12.0
Sample Weight (g)	*	1.0	2.5	1.4	1.6	1.1
Extract Weight (mg)	*	1250	500	140	320	90
Extract (ppm)	*	580	220	70	205	40
Hydrocarbons (ppm)	1	46	44	50	64	44
Hydrocarbons (% extr)	71	98	87	87	99	97
Alks (% hydrocarbons)						

RATIOS						
CPI-1	0.95	1.10	0.90	0.99	0.96	1.00
CPI-2	0.96	1.10	0.87	1.00	0.93	0.99
CPI-3	0.61	0.68	0.57	0.82	0.49	0.64
Bias	0.35	1.58	2.13	2.42	1.78	1.16
i-C19 / n-C17	0.72	0.61	0.77	0.54	0.59	0.56
i-C20 / n-C18	0.74	0.54	0.96	0.53	0.56	0.57
i-C19 / i-C20	0.54	0.60	0.64	0.45	0.83	0.47

LEGEND	
i - isoprenoid	n - normal
For definition of Ratios CPI-1,-2,-3 and Bias - see following page	

ALKANE GAS CHROMATOGRAPHY DATA

TABLE: 6D

SAMPLE DATA					
SAMPLE CODE	4500.0m	4500m			
SAMPLE TYPE	Mud	Ctgs			

COMPONENTS	QUANTIFIED NORMAL AND ISOPRENOID ALKANE ABUNDANCES (%)					
	n-C10					
n-C11						
n-C12						
n-C13						
n-C14						
n-C15	0.83	0.55				
n-C16	2.51	3.04				
n-C17	8.72	8.02				
n-C18	8.80	11.38				
n-C19	9.61	9.76				
n-C20	11.65	9.29				
n-C21	7.35	5.54				
n-C22	5.53	4.97				
n-C23	2.67	5.05				
n-C24	1.69	3.49				
n-C25	5.72	4.77				
n-C26	3.36	3.27				
n-C27	1.31	2.14				
n-C28	5.40	4.87				
n-C29	2.04	1.90				
n-C30	1.33	1.23				
n-C31	1.86	1.52				
n-C32	0.72	0.75				
n-C33	1.09	1.26				
n-C34	1.54	1.09				
n-C35	2.08	0.79				
n-C36		0.30				
i-C15 (Farnesane)						
i-C16		0.16				
i-C18 (Norpristane)	2.14	1.82				
i-C19 (Pristane)	5.15	5.39				
i-C20 (Phytane)	6.86	7.66				

GENERAL DATA					
Total Abundance (%)	100	100			
TOC (% of rock)	*	12.0			
Sample Weight (g)	*	1.6			
Extract Weight (mg)	*	135			
Extract (ppm)	*	85			
Hydrocarbons (ppm)	27	63			
Hydrocarbons (% extr)	99	68			
Alks (% hydrocarbons)					

RATIOS					
CPI-1	0.97	0.94			
CPI-2	0.97	0.91			
CPI-3	0.30	0.53			
Bias	1.99	1.72			
i-C19 / n-C17	0.59	0.67			
i-C20 / n-C18	0.78	0.67			
i-C19 / i-C20	0.75	0.70			

LEGEND					
i	- isoprenoid	n	- normal	For definition of Ratios CPI-1,-2,-3 and Bias - see following page	

ALKANE GAS CHROMATOGRAPHY DATA

TABLE: 6E

PHASE 2

5 MUD ADDITIVES - FURTHER ANALYSES

5.1 INTRODUCTION

As stated in Chapter 2 of this report, the analyses reported herein for Phase 2 of this study were undertaken with the aim of characterising the effects of altering the amount of additive material extracted along with any matrix effects that may result from mixing the additive with sand and clays.

5.2 EXTRACTION OF VARYING WEIGHTS OF PURE ADDITIVES

The analytical programme employed for this stage of the study involved the extraction of additive weights of 2.0g, 500 mg and 150 mg, using the same conditions as employed for the original extractions of the 10.0g-15.0g masses as reported in Phase 1 of this report. The composition of each extract was then obtained by Iatroscan fractionation. For comparison purposes the saturate fraction obtained from the 500 mg extraction of each additive was then analysed by gas chromatography. The results of the extraction/fractionation work are given on Table 7, and the gas chromatograms are shown as Figure 7, with the GC data on Table 10.

GENERAL DATA		SOLVENT EXTRACTION AND IATROSCAN FRACTIONATION DATA								
SAMPLE CODE	SAMPLE TYPE	SAMPLE WEIGHT g	EXTR. WEIGHT mg	EXTR. ppm	ALKS. % OF EXTR.	AROMS. % OF EXTR.	POLARS % OF EXTR.	HYDROCARBONS		ALKS. % OF HC
								ppm	% OF EXTR.	
PRODEFOAM	Add	*	*	*	39	13	48	*	52	75
	Add	10.0	10000	1E6	-	-	-	-	-	-
	Add	2.0	2000	1E6	30.2	5.8	64.0	360000	36	84
	Add	0.5	500	1E6	-	-	-	-	-	-
	Add	0.15	150	1E6	-	-	-	-	-	-
PROLUBE	Add	10.0	10000	1E6	-	-	-	-	-	-
	Add	2.0	2000	1E6	0.5	28.0	71.5	285000	29	2
	Add	0.5	500	1E6	-	-	-	-	-	-
	Add	0.15	150	1E6	-	-	-	-	-	-
PROBIO 2	Add	10.0	10000	1E6	-	-	-	-	-	-
	Add	2.0	2000	1E6	0.0	0.0	100.0	0	0	*
	Add	0.5	500	1E6	-	-	-	-	-	-
	Add	0.15	150	1E6	-	-	-	-	-	-
PROPOL REG	Add	10.0	3.1	310	4.2	0.6	95.2	15	5	87
	Add	2.0	2.5	1250	2.6	2.6	94.8	65	5	50
	Add	0.5	1.2	2400	2.8	2.1	95.1	118	5	57
	Add	0.15	3.3	22000	5.3	7.9	86.8	2904	13	40
XANTHAN POLYMER	Add	10.0	6.2	620	10.0	4.3	85.6	89	14	70
	Add	2.0	2.4	1200	5.6	4.2	90.2	118	10	57
	Add	0.5	1.4	2800	4.0	3.0	93.0	196	7	57
	Add	0.15	*	*	4.5	4.5	91.0	*	9	50
PROCAP	Add	15.0	18.8	1255	1.8	1.0	97.2	35	3	63
	Add	2.0	7.6	3800	2.6	7.7	89.7	391	10	25
	Add	0.5	1.6	3200	3.1	3.1	93.8	198	6	50
	Add	0.15	*	*	6.6	4.8	88.7	*	11	58
PAC POLYMER REG	Add	10.0	2.9	290	2.7	0.7	96.6	10	3	79
	Add	2.0	3.2	1600	2.8	4.2	93.0	112	7	40
	Add	0.5	1.7	3400	2.4	1.6	96.0	136	4	60
	Add	0.15	2.0	13350	5.5	4.1	90.4	1280	10	57
THERMOPOL	Add	10.0	7.7	770	4.3	2.2	93.5	50	6	66
	Add	2.0	2.0	1000	4.4	4.4	91.2	88	9	50
	Add	0.5	2.3	4600	3.7	3.7	92.6	340	7	50
	Add	0.15	1.7	11350	2.5	3.8	93.7	714	6	40

SOLVENT EXTRACTION AND IATROSCAN FRACTIONATION DATA FOR ADDITIVES
TABLE: 7A

GENERAL DATA		SOLVENT EXTRACTION AND IATROSCAN FRACTIONATION DATA								
SAMPLE CODE	SAMPLE TYPE	SAMPLE WEIGHT g	EXTR. WEIGHT mg	EXTR. ppm	ALKS. % OF EXTR.	AROMS. % OF EXTR.	POLARS % OF EXTR.	HYDROCARBONS		ALKS. % OF HC
								ppm	% OF EXTR.	
PAC POLYMER S	Add	12.0	115.4	9615	0.0	0.0	100.0	0	0	*
	Add	2.0	6.1	3050	0.0	2.2	97.8	67	2	0
	Add	0.5	4.7	9400	1.7	3.4	94.9	479	5	33
	Add	0.15	3.8	25350	1.8	2.7	95.5	1140	4	40
PAC POLYMER SL	Add	12.0	38.6	3215	4.1	19.9	76.0	770	24	17
	Add	2.0	14.7	7350	2.6	7.9	89.5	772	11	25
	Add	0.5	5.0	10000	1.7	5.2	93.1	690	7	25
	Add	0.15	4.2	28000	1.1	3.3	95.6	1232	4	25

SOLVENT EXTRACTION AND IATROSCAN FRACTIONATION DATA FOR ADDITIVES
TABLE: 7B

GENERAL DATA		SOLVENT EXTRACTION AND IATROSCAN DATA										
SAMPLE CODE	SAMPLE TYPE	SAMPLE WEIGHT g	SAND WEIGHT g	MIXTURE CRUSHED Y/N	EXTR. WEIGHT mg	EXTR. ppm	ALKS. % OF EXTR.	AROMS. % OF EXTR.	POLARS % OF EXTR.	HYDROCARBONS		ALKS. % OF HC
										ppm	% OF EXTR.	
PROLUBE	Add	2.0	8.0	N	1991	995300						
	Add	0.5	9.5	N	485	970200						
	Add	0.15	9.85	N	147	980000						
XANTHAN POLYMER	Add	2.0	8.0	N	3.6	1800						
	Add	0.5	9.5	N	1.9	3800						
	Add	0.15	9.85	N	1.8	12000						
PAC POLYMER REG	Add	2.0	8.0	Y	3.1	1550	11.7	1.7	86.6	208	13	87
	Add	2.0	4.0	Y	2.9	1450	12.8	10.3	76.9	335	23	55
	Add	2.0	4.0	N	3	1500	11.8	9.8	78.4	324	22	55
	Add	2.0	8.0	N	4	2000						
	Add	0.5	9.5	N	2.1	4200						
	Add	0.15	9.85	N	2.4	16000						
	Add	2.0	8.0	Y	2.6	1300	8.8	5.9	85.3	191	15	60
	Add	2.0	4.0	Y	2.4	1200	7.1	5.7	87.2	154	13	56
	Add	2.0	4.0	N	1.1	550	9.5	14.3	76.2	131	24	40

SOLVENT EXTRACTION AND IATROSCAN FRACTIONATION DATA FOR ADDITIVE/SAND MIXTURES

GENERAL DATA		SOLVENT EXTRACTION AND IATROSCAN DATA										
SAMPLE CODE	SAMPLE TYPE	SAMPLE WEIGHT g	FULLERS EARTH WEIGHT g	MIXTURE CRUSHED Y/N	EXTR. WEIGHT mg	EXTR. ppm	ALKS. % OF EXTR.	AROMS. % OF EXTR.	POLARS % OF EXTR.	HYDROCARBONS		ALKS. % OF HC
										ppm	% OF EXTR.	
XANTHAN POLYMER	Add	2.0	8.0	Y	3.6	1800	12.3	7.4	80.3	355	20	62
	Add	2.0	4.0	Y	3.7	1850	10.9	10.9	78.2	403	22	50
PAC POLYMER REG	Add	2.0	8.0	Y	2.2	1100	14.3	7.1	78.6	235	21	67
	Add	2.0	4.0	Y	4.0	2000	3.9	39.5	56.6	868	43	9

SOLVENT EXTRACTION AND IATROSCAN FRACTIONATION DATA FOR ADDITIVE/FULLERS EARTH MIXTURES
 TABLE: 9

SAMPLE DATA						
SAMPLE CODE SAMPLE TYPE	PRODEFOAM Add	PROLUBE Add	PROPOL REG Add	XANTHAN POLYMER Add	PROCAP Add	PAC POLYMER REG Add

COMPONENTS	QUANTIFIED NORMAL AND ISOPRENOID ALKANE ABUNDANCES (%)					
n-C10						
n-C11						
n-C12	1.59					
n-C13	3.98	0.14	0.80			0.20
n-C14	6.13	3.31	1.50			1.25
n-C15	9.01	8.67	2.11	0.72	0.42	1.89
n-C16	9.29	9.28	2.66	1.59	1.07	1.80
n-C17	9.46	7.18	4.21	3.07	2.64	4.31
n-C18	8.44	6.23	4.99	7.33	7.36	5.93
n-C19	6.60	4.57	5.57	6.75	8.57	7.08
n-C20	7.08	3.93	6.14	8.27	9.08	6.98
n-C21	5.10	2.87	6.59	8.22	8.97	6.09
n-C22	4.06	3.50	7.18	8.74	9.23	6.14
n-C23	2.75	2.14	5.29	6.64	7.64	5.17
n-C24	2.16	2.69	4.48	4.10	5.59	4.40
n-C25	1.01	3.37	4.77	7.39	5.66	5.45
n-C26	0.47	1.29	3.62	2.98	2.68	4.31
n-C27	0.13	3.00	3.70	4.59	3.56	5.29
n-C28	0.07	1.64	4.44	4.64	2.59	4.93
n-C29	0.02	4.45	5.01	5.40	4.99	5.72
n-C30	0.01	1.14	3.79	1.64	1.94	3.06
n-C31		11.41	5.91	5.75	5.58	4.96
n-C32		1.21	2.26	1.14	1.37	1.91
n-C33		2.08	2.93	3.08	2.43	2.45
n-C34		0.32	2.16	0.93	0.94	0.87
n-C35		0.56	1.70	0.73	1.11	2.55
n-C36		0.13	0.65	0.18	0.32	0.30
i-C15 (Farnesane)	3.24	0.38	0.33			0.31
i-C16	3.54	2.69	0.74		0.09	0.79
i-C18 (Norpristane)	3.39	3.47	0.98	0.48	0.53	0.61
i-C19 (Pristane)	7.29	4.65	2.85	1.17	1.49	1.79
i-C20 (Phytane)	5.19	3.69	2.66	4.45	4.16	3.46

GENERAL DATA						
Total Abundance (%)	100	100	100	100	100	100
Sample Weight (g)	0.5	0.5	0.5	0.5	0.5	0.5
Extract Weight (mg)	500	500	1.2	1.4	1.6	1.7
Extract (ppm)	1E6	1E6	2400	2800	3200	3400
Hydrocarbons (ppm)	-	-	118	196	198	136
Hydrocarbons (% extr)	-	-	5	7	6	4
Alks (% hydrocarbons)	-	-	57	57	50	60

RATIOS						
CPI-1	1.27	3.70	1.29	2.06	1.95	1.43
CPI-2	1.27	3.75	1.28	1.98	1.93	1.39
CPI-3	0.48	2.05	0.92	1.20	1.35	1.14
Bias	7.56	1.09	0.81	0.93	1.07	0.80
i-C19 / n-C17	0.77	0.65	0.68	0.38	0.56	0.42
i-C20 / n-C18	0.61	0.59	0.53	0.61	0.57	0.58
i-C19 / i-C20	1.40	1.26	1.07	0.26	0.36	0.52

LEGEND	
i - isoprenoid	n - normal
For definition of Ratios CPI-1,-2,-3 and Bias - see following page	

ALKANE GAS CHROMATOGRAPHY DATA FOR ADDITIVES

TABLE: 10A

SAMPLE DATA					
SAMPLE CODE	THERMOPOL	PAC POLYMER S	PAC POLYMER SL		
SAMPLE TYPE	Add	Add	Add		

COMPONENTS	QUANTIFIED NORMAL AND ISOPRENOID ALKANE ABUNDANCES (%)				
n-C10					
n-C11					
n-C12	0.07				
n-C13	0.02				
n-C14	0.09				
n-C15	0.33	0.84			
n-C16	0.54	1.16	0.09		
n-C17	1.28	1.89	1.06		
n-C18	4.30	2.96	1.05		
n-C19	5.54	3.97	2.61		
n-C20	6.14	4.08	5.18		
n-C21	8.42	4.39	6.75		
n-C22	11.09	4.47	6.98		
n-C23	11.31	5.37	6.98		
n-C24	8.53	5.61	5.40		
n-C25	7.06	7.81	6.33		
n-C26	4.66	7.41	5.70		
n-C27	4.40	8.56	6.48		
n-C28	3.70	6.80	4.59		
n-C29	5.14	9.21	11.26		
n-C30	2.43	4.67	3.45		
n-C31	5.17	8.76	13.93		
n-C32	1.67	2.36	2.00		
n-C33	2.37	3.74	5.66		
n-C34	1.08	1.16	1.36		
n-C35	1.40	1.77	1.82		
n-C36	0.37	0.32	0.34		
i-C15 (Farnesane)	0.01				
i-C16	0.09	0.23			
i-C18 (Norpristane)	0.18	0.37			
i-C19 (Pristane)	0.54	0.80	0.27		
i-C20 (Phytane)	2.06	1.32	0.74		

GENERAL DATA					
Total Abundance (%)	100	100	100		
Sample Weight (g)	0.5	0.5	0.5		
Extract Weight (mg)	2.3	4.7	5		
Extract (ppm)	4600	9400	10000		
Hydrocarbons (ppm)	340	479	690		
Hydrocarbons (% extr)	7	5	7		
Alks (% hydrocarbons)	50	33	25		

RATIOS					
CPI-1	1.47	1.56	2.31		
CPI-2	1.44	1.51	2.20		
CPI-3	1.05	1.20	1.26		
Bias	0.66	0.33	0.33		
i-C19 / n-C17	0.42	0.42	0.25		
i-C20 / n-C18	0.48	0.45	0.70		
i-C19 / i-C20	0.26	0.60	0.36		

LEGEND		
i - isoprenoid	n - normal	For definition of Ratios CPI-1,-2,-3 and Bias - see following page

ALKANE GAS CHROMATOGRAPHY DATA FOR ADDITIVES

TABLE: 10B

SAMPLE DATA						
SAMPLE CODE	PROLUBE	XANTHAN POLYMER				
SAMPLE TYPE	Add	Add				

COMPONENTS	QUANTIFIED NORMAL AND ISOPRENOID ALKANE ABUNDANCES (%)					
n-C10						
n-C11						
n-C12	0.39	0.02				
n-C13	0.69	0.12				
n-C14	7.65	0.06				
n-C15	10.29	1.26				
n-C16	7.94	1.89				
n-C17	5.65	2.31				
n-C18	5.44	1.77				
n-C19	3.90	1.86				
n-C20	3.11	4.35				
n-C21	2.00	6.36				
n-C22	2.28	8.77				
n-C23	1.52	6.68				
n-C24	1.88	6.44				
n-C25	5.50	7.38				
n-C26	1.16	5.28				
n-C27	1.94	5.81				
n-C28	4.31	4.77				
n-C29	3.44	7.55				
n-C30	1.36	4.25				
n-C31	8.42	7.85				
n-C32	1.10	2.83				
n-C33	1.69	4.10				
n-C34	1.28	2.34				
n-C35	0.59	1.75				
n-C36		0.82				
i-C15 (Farnesane)	1.51	0.00				
i-C16	4.22	0.58				
i-C18 (Norpristane)	3.17	0.71				
i-C19 (Pristane)	4.04	1.05				
i-C20 (Phytane)	3.52	1.05				

GENERAL DATA						
Total Abundance (%)	100	100				
Sample Weight (g)	2.0	2.0				
Sand Weight (g)	8.0	4.0				
Mixture Crushed Y/N	N	Y				
Extract Weight (mg)	1991	2.9				
Extract (ppm)	995300	1450				
Hydrocarbons (ppm)	-	335				
Hydrocarbons (% extr)	-	23				
Alks (% hydrocarbons)	-	55				

RATIOS						
CPI-1	2.21	1.53				
CPI-2	2.32	1.52				
CPI-3	0.71	1.16				
Bias	0.94	0.43				
i-C19 / n-C17	0.72	0.46				
i-C20 / n-C18	0.65	0.59				
i-C19 / i-C20	1.15	1.00				

LEGEND		
i - isoprenoid	n - normal	For definition of Ratios CPI-1,-2,-3 and Bias - see following page

ALKANE GAS CHROMATOGRAPHY DATA FOR ADDITIVE/SAND MIXTURES

TABLE: 11

SAMPLE DATA						
SAMPLE CODE	XANTHAN POLYMER					
SAMPLE TYPE	Add					

COMPONENTS	QUANTIFIED NORMAL AND ISOPRENOID ALKANE ABUNDANCES (%)					
n-C10						
n-C11						
n-C12	0.01					
n-C13	0.05					
n-C14	0.11					
n-C15	1.01					
n-C16	1.21					
n-C17	2.87					
n-C18	4.38					
n-C19	3.82					
n-C20	3.96					
n-C21	3.83					
n-C22	4.30					
n-C23	4.10					
n-C24	3.83					
n-C25	3.94					
n-C26	3.41					
n-C27	4.42					
n-C28	5.24					
n-C29	7.92					
n-C30	6.61					
n-C31	9.49					
n-C32	5.57					
n-C33	5.80					
n-C34	4.00					
n-C35	2.80					
n-C36	1.74					
i-C15 (Farnesane)	0.03					
i-C16	0.59					
i-C18 (Norpristane)	0.48					
i-C19 (Pristane)	1.99					
i-C20 (Phytane)	2.52					

GENERAL DATA						
Total Abundance (%)	100					
Sample Weight (g)	2.0					
Sand Weight (g)	4.0					
Mixture Crushed Y/M	Y					
Extract Weight (mg)	3.7					
Extract (ppm)	1850					
Hydrocarbons (ppm)	403					
Hydrocarbons (% extr)	22					
Alks (% hydrocarbons)	50					

RATIOS						
CPI-1	1.28					
CPI-2	1.29					
CPI-3	1.02					
Bias	0.40					
i-C19 / n-C17	0.70					
i-C20 / n-C18	0.58					
i-C19 / i-C20	0.79					

LEGEND						
i	- isoprenoid	n	- normal	For definition of Ratios CPI-1,-2,-3 and Bias - see following page		

ALKANE GAS CHROMATOGRAPHY DATA FOR ADDITIVE/FULLERS EARTH MIXTURES

TABLE: 12

6 REFERENCES

- ANCHOR DRILLING FLUIDS, 1990a. Toxicological data sheet - Lubsol/Prolube.
- ANCHOR DRILLING FLUIDS, 1990b. Toxicological data sheet - Biosafe/Probio 2.
- ANCHOR DRILLING FLUIDS, 1990c. Toxicological data sheet - Claycap/Procap.
- ANCHOR DRILLING FLUIDS, 1990d. Toxicological data sheet - Thermopol/Hostadrill.
- ANCHOR DRILLING FLUIDS, 1991a. Toxicological data sheet - Nofoam/Prodefoam.
- ANCHOR DRILLING FLUIDS, 1991b. Toxicological data sheet - Pacseal/Propol/Pac Polymer (Reg/S/SL).
- ANCHOR DRILLING FLUIDS, 1991c. Toxicological data sheet - Thixopol/XC Polymer/XCD Polymer/Xanthan Gum Polymer.
- GEOCHEM, 1990. Reservoir geochemistry, well 7228/9-1 (Hydro), Report No. 3228. (Confidential report, Norsk Hydro Report No. R-040188).
- NORSK HYDRO, 1990. Geochemical data well 7228/9-1, Report No. R-044566. (Confidential report).
- WORLD OIL, 1989. World Oil's 1989 guide to drilling, completion and workover fluids. World Oil, June 1989, p. 59-96.

APPENDIX 1
ABBREVIATIONS USED IN ANALYTICAL DATA SHEETS

a/s	-	as above	MDST	-	mudstone
Ac	-	acritarchs	med	-	medium
ADD	-	mud additive	MET	-	metamorphic rocks
Al	-	algae	mic	-	mica/micaceous
Am	-	amorphous	micr	-	micritic
ang	-	angular	min	-	mineral
ANH	-	anhydrite	mnt	-	minor
aren	-	arenaceous	mod	-	moderate
arg	-	argillaceous	mtl	-	mottled
BAS	-	basalt	n-	-	normal
bd	-	bedded/bedding	NA	-	not available
B(IT)	-	bitumen/bituminous	nod	-	nodule/nodular
bl	-	blue	NS	-	no sample
bid	-	bleached	occ	-	occasional
bik	-	black	ol	-	olive
bri	-	brilliant	ool	-	oolitic
brn	-	brown	orng	-	orange
calc	-	calcareous	OS	-	oil stain
CALT	-	calcite	P	-	picked lithology
carb	-	carbonaceous	pal	-	pale
CGL	-	conglomerate	Ph	-	phytane
CHK	-	chalk	pnk	-	pink
CHT	-	chert	por	-	porous/porosity
CLYST	-	claystone	pp	-	purple
CT	-	cement	Pr	-	pristane
Comp	-	composite	pred	-	predominantly
crs	-	coarse	Prt	-	present
CSG	-	casing point/shoe	PYR/pyr	-	pyrite/pyritic
Ctgs	-	ditch cuttings	QTZ(T)	-	quartz(ite)
Cu	-	cuticle	Re	-	resin
C(vd)	-	caved	R(ew)	-	reworked
decarb	-	decarbonated	rnd	-	round(ed)
D1	-	dinocysts	Sap	-	sapropel
dk	-	dark	sbng	-	subangular
DLT	-	dolerite	sbrd	-	subrounded
DOL/dol	-	dolomite/dolomitic	SCI	-	spore colour index
dsk	-	dusky	Sf	-	semifusinite
Ex	-	exinite	sft	-	soft
Exs	-	exsudatinitite	SH	-	shale
extr	-	extracted	shly	-	shaly
f	-	fine	sil	-	siliceous
fel	-	feldspathic	sls	-	slickenside surface
fer	-	ferruginous	SLA	-	slate
flu	-	fluorescence	SLT(ST)	-	silt(stone)
fm	-	formation	slty	-	silty
foss	-	fossils/fossiliferous	SND	-	sand
fr	-	friable	sndy	-	sandy
frac	-	fracture	Sp	-	spores
frags	-	fragments	SST	-	sandstone
Fu	-	fusinite	st	-	stained
GLC/glc	-	glauconite/glauconitic	stks	-	streaks
gn	-	green	suc	-	sucrosic
grd	-	graded/grading to	surf	-	surface
grns	-	grains	SWC	-	side wall core
GY	-	grey	TD	-	total depth
GYP	-	gypsum	TOC	-	total organic carbon
HAL	-	halite	tr	-	trace(s)
hd	-	hard	trns	-	transparent
hor	-	horizontal	v	-	very
H(RV)	-	high reflecting vitrinite	vgt	-	variegated
i-	-	iso-	Vit	-	vitrinite
i/b	-	inter-bedded	vn	-	vein
IGN	-	igneous rocks	VOLC	-	volcanic rocks
inc	-	including	VR	-	vitrinite reflectivity
Inert	-	inertinite	wht	-	white
lam	-	laminae/laminated	xln	-	crystalline
LCM	-	lost circulation material	yel	-	yellow
LIG/Lig	-	lignite/lignitic	-	-	no analysis carried out
lns	-	lens(es)	*	-	analysed but no data obtained
L(RV)	-	low reflecting vitrinite	gy-gn	-	greyish green
LST	-	limestone	gy/gn	-	grey-green (gradation)
lt	-	light	gn-gy	-	greenish grey
mass	-	massive			

Note: (Maturity data tables only). Number in brackets refers to number of reflectivity values averaged to give quoted result. Preferred values for indigenous phytoclasts are listed first.

APPENDIX 2

ANALYTICAL PROCEDURES AND TECHNIQUES

This appendix summarises the main steps in the analyses carried out in the Robertson Research International Ltd. petroleum geochemistry laboratories. Analytical pathways are shown on the flow chart (Appendix Figure 1) and details of laboratory procedures and techniques are given in the text. These may in certain circumstances be adapted to suit particular samples or conditions. Interpretation guidelines are also defined.

1. Sample Preparation

General

Samples are received into the laboratories in the forms of well-site canned ditch cuttings, bagged ditch cuttings in various stages of preparation from wet, unwashed to dried, washed; sidewall cores, conventional cores, outcrop samples, crude oil samples and gas samples. Each sample is assigned a number which is entered into a computer system to monitor sample selection and progress. Preparation techniques are directed towards obtaining clean samples, free of drilling mud and mud additives, obvious caving contamination and indeterminate fine material. Washing with cold water is standard but further washing with solvent (dichloromethane, DCM) is carried out if oil-based mud is present, after which samples are dried, described and individual lithologies hand-picked where practicable. Samples are rough crushed to approximately pea-sized fragments for kerogen preparation or finely milled for chemical analysis.

Kerogen Preparation

Kerogen concentrates for microscopic examination and elemental analysis are prepared using standard palynological procedures but omitting oxidation or acetolysis. Acid maceration involves the use of hot hydrochloric acid (HCl) to remove carbonates and hot 60% hydrofluoric acid (HF) to remove or break down silicates. Mineral residues are separated from the kerogen by a combination of ultrasonic vibration and zinc bromide flotation. Kerogen samples for spore colour and kerogen typing are mounted on glass slides in glycerin jelly, those for vitrinite reflectivity are dried and mounted in epoxy resin. Kerogen residues are stored in methanol.

2. Maturity Evaluation

The techniques employed for interpreting maturity and thermal history in these laboratories are based mainly on spore colouration and vitrinite reflectivity measurement, supplemented by data obtained from airspace gas and gasoline analysis, pyrolysis T_{max}, and hydrocarbon analysis including gas chromatography and gas chromatography-mass spectrometry.

Spore Colouration

Sporomorph colour is assessed using a >20 μ sieved kerogen fraction viewed in transmitted light on a standard palynological microscope. Unusual hues are checked using incident blue/UV light fluorescence. Measurement is made by eye against reference sets of single grain spore mounts and trained operators achieve a high degree of accuracy and reproducibility. The 1 to 10 Spore Colour Index (SCI) scale was designed for linearity with increasing depth and temperature and correlates approximately with the following zones of oil generation: 1.0 to 3.5, immature; 3.5 to 5.0, early mature, generation of low gravity oils (28 to 35 °API); 5.0 to 7.0, middle mature, generation of medium gravity oils (35 to 42 °API); 7.0 to 8.5, late mature, generation of light oils (>42 °API) and condensates; 8.5 to 10, post mature, generation of condensate, wet gas and, ultimately, dry gas. Linearity of scale is of great value in prediction, by extrapolation, of the depth to any part of the oil generation sequence. The value of SCI measurement lies in the objective selection of measured grains, so minimising problems of caving and reworking, and in its more direct correlation against oil generation than vitrinite reflectivity measurement. Limitations in its use concern the difficulty of correlation against other colour scales and the insensitivity of the scale in the late to post mature region. Anomalous colours may result from bleaching or staining during deposition and diagenesis. The correlation of SCI against Thermal Alteration Index (TAI) given on the SCI versus depth plot in the reports was made by direct comparison of Staplin's standard slides with SCI standard slides.

Vitrinite Reflectivity

The majority of preparations examined under reflected light in these laboratories are made using >20 μ sieved kerogen, mounted in resin blocks and polished with carborundum and alumina although total kerogen may be used when sample size is

limited. Picked coals, organic-rich shales or limestones containing solid bitumen are mounted directly in resin blocks and polished in the usual way. Measurement is made on a Leitz Orthoplan microscope fitted with an MPV Compact photometer which feeds values direct to a desk top computer for data processing from each sample. The system is calibrated against glass standards and reflectance values are expressed as arithmetic means of measurements taken in oil immersion (R_o or R_m oil). R_{max} and R_{min} may be measured and quoted in certain circumstances but the difference is insignificant below about R_o 1.0%. Some operator selection of particles during measurement is essential and obvious contaminants or non-vitrinitic material are noted but not necessarily quoted. The value quoted on data tables is that which is interpreted as most appropriate, but other possibilities may also be given. Plotted figures assume a logarithmic increase of reflectance with depth. R_o 0.5% is a widely accepted threshold value for the onset of oil generation, although as the kinetics of oil generation may not be identical to those of vitrinite reflectivity development this must be seen only as a general guide. The floor for oil generation is characterised by a reflectance value of about 1.3%. Wet gas generation peaks at a value of about 1% and ceases at the 2% level. Dry gas generation peaks at a reflectance of about 1.5% and ceases at the 3% to 4% level. Correlation of reflectance values with other maturity parameters may not be universal because of time-temperature factors and is best made on a local basis.

Reflectivity measurement is a widely used and versatile tool which may be readily calibrated against easily obtained standards. It is applicable over a wide range of maturity stages from immature to post mature (0.2% to 5% R_o). High surface intercepts on plotted figures and discordances at faults and unconformities can give realistic estimates of the amount of section missing. It is of limited value in Early Palaeozoic sections where land plant material is absent, although a general guide to maturity may be obtained from chitinous organic matter. Even a skilled operator may have difficulty in distinguishing indigenous vitrinite from some forms of inertinite, anomalously reflecting "pseudovitrinite", cavings and reworked fragments.

Airspace Gas Analysis

Wet cuttings are collected at the well site and sealed in partly full cans containing bactericide. In the laboratory, the airspace (headspace) gas is extracted using a can piercer fitted with a septum and analysed by gas chromatography. The proportions of methane, ethane, propane, iso- and n-butane are calculated from integrated peak areas by comparison with a standard mixture of these gases. Methane is the dominant gas in immature and post mature sediments, comprising 90-100% of total gas, falling to 30-70% in mature sediments. The onset of maturity for oil generation (SCI 3.5) is characteristically marked by an increase in wet gas (C_2-C_4) to between 10 and 20% with further increases in maturity indicated by a decrease in the ratio of iso- to n-butane. Ratios of >1.0 are typical for immature sediments and <0.5 are usual in mature sediments. Departures from composition versus depth trends may be useful in indicating migrant gas at faults, unconformities or reservoir rocks but limit the method as a reliable maturity indicator. Airspace gas analysis is an inexpensive and rapidly executed method of screening samples for further maturity and hydrocarbon content determinations.

Gasoline Analysis and Cuttings Gas Analysis

Cuttings samples received wet, preferably in sealed containers, are suitable for gasoline and cuttings gas analysis. A portion of the washed cuttings sample is retained wet, pulverised in a sealed shaker and warmed to expel the C_1 to C_7 hydrocarbon components into the shaker airspace. A sample of this airspace gas is then removed and analysed by gas chromatography either for cuttings gas (C_1 to C_4) or gasolines (C_4 to C_7). Up to 28 hydrocarbon components are identified in the C_4 to C_7 range and their relative proportions calculated from integrated peak areas with reference to standard mixtures. Immature source rocks yield low total abundances and limited numbers of components whereas mature source rocks usually contain a full complement of identified hydrocarbons with the onset of maturity indicated by a rapid rise in total gasoline abundances with depth. Anomalous amounts of gasolines may mark the presence of oil stain. Gasolines may be used in oil to oil or oil to source rock correlations but the concentration of some of the measured components is not only a function of source but also depends on maturity, migration and alteration in the reservoir. Using the most stable compounds, pairs with similar chemical structure and boiling points are reduced to pair ratios and compared with the same pair ratios in other oils or possible source rocks. Gasoline analysis is a valuable tool in that it measures directly the hydrocarbons being generated from a sediment but its sensitivity in detecting traces of oil places constraints on its use as a maturity indicator.

Rock-Eval Pyrolysis, Gas Chromatography (GC) and Gas Chromatography-Mass Spectrometry (GC-MS) in Maturity Analysis

These three analytical processes measure parameters which are functions of both maturity and kerogen type. Data from them may give a general guide to maturity but if the kerogen types are known, more specific conclusions may be drawn. From Rock-Eval data, the temperature of maximum rate of pyrolysis, T_{max} , is the most useful datum; gas chromatograms of alkanes, separated from source rock extracts or oils, yield carbon preference indices (CPI) and isoprenoid ratios; GC-MS quantitative fragmentograms provide abundance ratios for specific compounds which are particularly useful in assessing the level of maturity at which source rock hydrocarbons or oils have been generated. All these supplementary data may be used to confirm results from visual analysis or supplant them if poor or unavailable.

3. Source Rock Evaluation

Total Organic Carbon Content (TOC)

Organic carbon values are obtained by treating 0.1g of crushed rock sample with hot, concentrated HCl to remove carbonates. The washed residue is filtered on to a glass fibre pad and ignited in a Leco carbon analyser. For screening purposes, samples are analysed singly but where further analyses, such as pyrolysis or solvent extraction are anticipated, a duplicate sample is run. Blanks and standards are run as routine and where values from duplicated samples do not concur within strict accuracy limits, they are rerun. Where samples are heavily stained with oil, either from natural deposits or drilling mud, TOC is repeated on the dried, solvent extracted sample.

TOC measurement is fundamental in assessing source rock quality since when combined with kerogen type and maturity, a full description of the potential to generate oil may be given. It is found in practice that sediments containing less than 0.3% TOC are unlikely to have any source potential, those containing between 0.3% and 1% may be marginal sources but the better quality sources contain in excess of 1% TOC. Screening by TOC is therefore an inexpensive and rapid method of selection of samples for further analysis in source potential evaluation.

Rock-Eval Pyrolysis

Pyrolysis data are obtained using the IFF-Fina Rock-Eval apparatus. 100 mg of crushed, whole rock either from bulk sample or picked lithology is weighed accurately into a crucible and introduced into a furnace at 250°C. Free hydrocarbons (roughly equivalent to solvent extractable hydrocarbons) are volatilised and quantified by flame ionisation detector (FID) to give Peak 1 (S_1 , ppm). The furnace temperature is increased to 550°C at 25°C/minute and within this range, kerogens crack to give hydrocarbons, measured by FID to give Peak 2 (S_2 , ppm) and carbon dioxide, measured by thermal conductivity detector (TCD) to give Peak 3 (S_3 , ppm). The temperature at the maximum rate of evolution of cracked volatiles (T_{max}) is measured automatically but can also be monitored visually. The instrument is calibrated daily using standards both at the beginning of the work period and at regular intervals thereafter and crucible blanks are run as routine. The tabulated data in reports comprise the following parameters:

T_{max} °C - temperature of maximum rate of Peak 2 hydrocarbon evolution.

Hydrogen Index (HI) - S_2/TOC (mg/g) or ratio of released hydrocarbon to organic carbon content. This is a measure of the hydrocarbon generating potential remaining in the kerogen as opposed to that of the whole rock.

Oxygen Index (OI) - S_3/TOC (mg/g) or ratio of released carbon dioxide to organic carbon content.

Production Index (PI) - S_1/S_1+S_2 , or ratio of the amount of hydrocarbons released in the first stage of heating to the total amount of hydrocarbons released and cracked during pyrolysis.

Potential Yield (PY) - S_2 (ppm) or total of hydrocarbons released during cracking of kerogen compared to original weight of rock.

T_{max} , hydrogen index and oxygen index are each functions of both maturity and kerogen type. Using published and empirical data, it has been possible to assemble a model to show the relationships of these factors to maturity as measured by spore colouration and vitrinite reflectivity for a selection of pure kerogen types. The kerogen types used are algal sapropel (type I), waxy sapropel (type II), vitrinite (type IIIA) and inertinite (type IIIB) and a computer program has been devised by which the amounts of these components may be calculated from the HI, OI, T_{max} and maturity

data for any sample. These are the values expressed in the "kerogen composition by calculation" columns tabulated in the reports.

The hydrogen index is a measure of the hydrocarbon generating potential of the kerogen and is analogous to the atomic H/C ratio. Immature, organically rich source rocks and oil shales give values above 500, mature oil source rocks give values between 200 and 550. For a given kerogen type, these values progressively diminish with increasing maturity.

The temperature of maximum rate of pyrolysis depends partly on the kerogen type but the transition from immature to mature organic matter is marked by temperatures between 415° and 435°C. The maturity transition from oil and wet gas generation to dry gas generation is marked by temperatures between 455° and 460°C. In practice, greater variation than these ideal temperature ranges may be seen, but they are nevertheless useful as general guides to the level of maturity attained by the sediment.

The production index increases with maturity from values near zero for immature organic matter to maximum values of 0.15 during the late stages of oil generation. Anomalously high values indicate the presence of oil or contaminants. The potential yield is an indication of the predicted yield of hydrocarbons from the source rock at optimum maturity and is a measure of the quality of the source rock. For immature sediments, values of 0 to 2000 ppm of hydrocarbon characterise a poor source rock, 2000 to 6000 ppm fair, 6000 to 20 000 ppm good and above 20 000 ppm very good.

Pyrolysis techniques have in recent years provided a major advance in the assessment of source rock quality and generating potential. Hydrocarbon yields from immature source beds examined on-structure may be translated into actual oil productivity from the same beds in mature basinal, off-structure situations. Models relating maturity and kerogen type may be used to define original source rock quality grades which are of great value in mapping organic facies. Amorphous kerogen types, indistinguishable in microscopic preparations over a wide range of chemical properties, may be readily differentiated by pyrolysis. The problem of analysing bulk samples containing mixed kerogens has been largely overcome by the kerogen type/maturity model and anomalous results arising from the presence of caving contamination and drilling mud additives can usually be explained by inspection. High oxygen indices sometimes occur as a result of the presence of metastable carbonates and in such cases the sample is acid decarbonated and re-run.

Visual Examination of Kerogen Concentrates

All palynological preparations on which SCI determinations are made are also examined for kerogen type. Visual estimations of the relative abundance of the broad groups vitrinite, inertinite and sapropel are made on the total kerogen slide mount but reference is also made to the >20 μ sieved fraction to assist in identification. The scheme of identification is shown in Appendix Table 1. Full use is made of incident blue or UV light in distinguishing immature or early mature oil-prone kerogen from gas-prone kerogen.

Extract Analysis

The soluble organic materials present in rocks can be extracted with organic solvents, fractionated and analysed. The type and amount of material extracted depends largely upon the nature of the contained kerogen and its maturity, although the presence of migrant oil or drilling contamination may be the determining factors.

A maximum of 40g of crushed sample is extracted for a minimum of 12 hours in a Soxhlet apparatus using laboratory redistilled DCM. The solvent and the more volatile components (approximately up to n-C₁₅) are lost by evaporation in an air flow and the resulting total extract is weighed, dissolved in hexane and separated into alkane (saturate) hydrocarbon, aromatic hydrocarbon, resene and asphaltene (polar) fractions by silica adsorption chromatography in the Introscan process.

Larger fractions, suitable for further analysis, are obtained by column chromatography. The extract is run through a short glass column packed with silica and alumina and eluted with hexane (to give the saturate fraction), (3:1 hexane: toluene mixture (to give the aromatic fraction) and methanol (to give the polar, or resene and asphaltene, fraction). A small proportion of non-eluted polar compounds usually remains on the column.

The data tabulated in reports comprise the following parameters:

Total extract - soluble organic matter, heavier than about $n\text{-C}_{15+}$, expressed as ppm of weight of rock.

Hydrocarbons - sum of alkane and aromatic hydrocarbons, expressed as ppm of weight of rock.

Extract % of organic carbon (EPOC) - $\frac{\text{total extract ppm}}{\text{TOC} \times 100}$; the extractability.

Hydrocarbons mg/g of organic carbon - total hydrocarbons normalised to 1g of organic carbon.

Hydrocarbons % extract - total hydrocarbons as a proportion of total extract.

Alkanes % hydrocarbons - the proportion of alkanes (saturates) in the total hydrocarbons. The proportion of aromatics is (100 minus this value) expressed as a percentage.

The extractability of oil-prone sapropelic organic matter increases rapidly in the oil generation zone and diminishes to very low values in post mature sediments. Overall the extractability of sapropelic organic matter is greater than that of gas-prone humic organic matter for similar levels of maturity. Samples with extractabilities of greater than 20% generally contain migrant oil or are contaminated with mud additives.

As maturation proceeds in the oil generation zone the proportion of hydrocarbons in the total extract increases from less than 20% to a maximum in the most productive horizons of around 60%. This trend is reversed as the oil-condensate zone is entered. The relative proportions of alkanes to aromatics can be used as a check for low levels of contamination. Fractions of the extract, separated by column chromatography are retained for further analysis by gas chromatography or for stable carbon isotope determination.

Capillary Gas Chromatography of C_{15+} Alkanes

A portion of the Soxhlet extract is eluted with hexane through a short silica column to yield the saturate hydrocarbon fraction. This fraction is evaporated in a stream of dry nitrogen at room temperature. A small portion of the fraction is then taken up in hexane and introduced into a 25 metre, wall-coated, open tubular glass capillary column coated with OV-1, or equivalent, mounted in a Carlo Erba gas chromatograph which is temperature programmed from 70°C to 270°C at 3°C/minute.

C_{15+} chromatograms are inspected for the distributions of n -alkanes, and the presence and abundance of isoprenoids (particularly pristane and phytane), steranes and triterpanes and unresolved envelopes of naphthenic compounds. The ratios pristane:phytane and pristane: $n\text{-C}_{17}$ are calculated. Carbon Preference Index (CPI) values quoted are those as defined by Philippi as the ratio $2C_{29}$ to $(C_{28}+C_{30})$ unless otherwise stated. Chromatography may reveal information about the kerogen type of the source rock, its maturity and condition of deposition and, if migrant oil is present, whether this has been water-flushed or biodegraded. Contaminant drilling mud additives may be identified.

Capillary Gas Chromatography of Aromatic and Branched/Cyclic Alkanes

The aromatic portion of the Soxhlet extract is eluted from a short silica/alumina column by a hexane/toluene mixture. The dried fraction is taken up in DCM and introduced into a 25 metre, wall-coated, open tubular glass capillary column coated with OV-1, or equivalent, mounted in a Carlo Erba gas chromatograph which is temperature programmed from 70°C to 270°C at 3°C/minute.

Branched chain alkanes are separated from normal alkanes by urea adduction and treated as for total alkanes.

Gas Chromatography-Mass Spectrometry

Mass spectrometry is a technique in which molecules are bombarded with high energy electrons causing ionisation and fragmentation of the molecules into ions of varying mass(m) and charge(z). The way in which a molecule fragments into ions of various m/z value is known as its fragmentation pattern, or mass spectrum and is unique. When linked to a gas chromatograph the mass spectrometer can be used in two different modes:

1. Full Scan Mode: A mass spectrum is obtained of each peak eluting from the gas chromatograph and a structural identification of the compound producing that peak can be made.
2. Multiple or Single Ion Monitoring Mode: The mass spectrometer is tuned to certain m/z values to detect whether a compound, eluting from the gas chromatograph, fragments to give an ion at that value. Certain fragmentations are indicative of specific compound types and the most commonly monitored fragment ions used in petroleum geochemistry are those with m/z values of 191, 217 and 259 which are the principal fragment ions obtained from groups of alkanes known as triterpanes, regular steranes and rearranged steranes respectively. These are compounds containing 27 to 35 carbon atoms arranged in a polycyclic, normally 4 or 5 ring, structure, occurring in the $n-C_{26}$ to $n-C_{35}$ region of a gas chromatogram. The basic molecular skeletons of these compounds are very similar to those of the original organic matter deposited in the sediment and so these 191, 217 and 259 distribution plots, known as mass fragmentograms or mass chromatograms, form a pattern characteristic of the source material. This technique of "fingerprinting" is also one of the more exact methods of correlating an oil to its source, or to another oil.

Carbon Isotope ($^{13}C/^{12}C$) Ratio Analysis

Carbon has two stable isotopes, the more abundant ^{12}C isotope and the heavier ^{13}C isotope, which in nature forms about 1% of carbon. Deviations from the $^{13}C/^{12}C$ ratio are extremely small and carbon isotope ratios, as measured by mass spectrometry, are expressed as deviations from a standard, the Pee Dee Belemnite carbonate (PDB standard) in parts per thousand (parts per mil; ‰). Positive deviations indicate ^{13}C enrichment and conversely, negative deviations indicate ^{13}C impoverishment.

While the carbon isotope ratios of oils and rock extracts can range from -20 to -32 ‰ depending on the source organic matter type, the difference between a specific oil and its source is small. Measurements are usually made on the C_{15+} alkane and aromatic hydrocarbon fractions separately and there should be no more than 1 ‰ difference between the oil and its source for either fraction. If there is any doubt that the source rock extracts are not indigenous to the source rock kerogen, the carbon isotope ratio of the extracted source rock kerogen can be measured.

Pyrolysis-Gas Chromatography

The hydrocarbon pyrolysate derived from thermal, anhydrous cracking of kerogen is analysed by capillary gas chromatography. A few mg of rock, kerogen or asphaltene is heated to 600°C for 20 seconds in the injector of a gas chromatograph. The chromatograph oven is kept at -30°C during pyrolysis and then raised to 300°C at a programmed rate of 7.5°C/minute. Chromatograms produced this way are often very different from those of source rock extracts or oils in that branched and cyclic isomers are generated freely giving numerous, closely spaced peaks, along with unsaturated, alkene (olefin) hydrocarbons. The "doublet" peaks often observed in these chromatograms comprise alkene-alkane pairs, the first eluting, and usually smaller peak, being the alkene. The chromatograms range from C_1 to C_{30} or above and although variable, are broadly characteristic of source rock type. Gas-prone kerogen cracks to give a more limited molecular weight range of products, concentrated towards the light ends, whereas oil-prone kerogen gives more prominent alkene-alkane doublets in the C_{12} to C_{30} region. The largest peak from both types is usually methane.

Elemental Analysis

Total (unsieved) kerogen is prepared as described in Section 1. The dried material is combusted in oxygen in an elemental analyser and the oxides of carbon, hydrogen, nitrogen and sulphur are measured. The unburnt residue is the ash content. Oxygen is usually calculated by difference but can be determined separately if required. Results are quoted as percentage weights of C, H, O, N, S and Ash with the atomic ratio H/C and O/C calculated and plotted on the standard van Krevelen diagram. The relative amounts of C, H and O present in organic matter are dependent on both source and maturity. At known maturity levels, some measure of source quality may be determined. Limitations of the method in source rock assessment involve the difficulty of obtaining pure kerogen (in particular, free from pyrite) and the lack of a simple, direct determination of oxygen content.

4. Oil Analysis

RI laboratories offer a wide range of oil analyses both for geochemical purposes and industrial use. Physical property determinations are based mainly on IP methods and are available for lubricating oils, fuels and greases as well as crudes. Frequently measured properties of crude oils presented in geochemistry reports include: API gravity, pour point, viscosity and contents of water, sulphur, wax, asphaltene, nickel, vanadium and other metals. Chemical analysis of oils involves the following:

Whole oil gas chromatography - using split syringe injection and a temperature programme from -20°C or -30°C up to 270°C at 4°C/minute.

Associated gas - if oil has high gas/oil ratio.

Gasoline analysis - as for gasolines in rock samples but a weighed quantity of oil is used.

Topping of the oil - this is equivalent to the removal of the fraction boiling below about 210°C and gives a more standardised product for comparison of gas chromatograms of the C₁₅₊ fraction.

Column chromatography and gas chromatography - as for solvent extracts. Analysis is carried out on topped oil.

5. Gas Analysis

The hydrocarbon gases, C₁ to C₄, may be collected from the airspace of sealed canned samples or may be received from well-site tests in a special sealed gas cylinder (gas mouse). Chromatographic separation of the C₁ to C₄ gases is effected as described under airspace gas analysis. In addition, the separated gas components may be analysed for stable carbon and hydrogen isotope composition which may provide valuable clues to the origin of the gas.

6. Solid Bitumen Analysis

In some oil fields, problems are encountered where bitumen developments form continuous or patchy layers within reservoirs, dividing the pay zones and acting as barriers to natural fluid movement or inhibiting enhanced oil recovery techniques. Integrated geochemical and sedimentological studies aim to produce geological models capable of predicting the occurrence of bitumen layers and their likely thickness and ability to act as permeability barriers. Of further concern are the past or present relationships between the bitumen and reservoir oil, their source rocks and the timing of bitumen formation.

Analysis schemes involve screening of samples by assessing the amount of bitumen in polished core pieces using reflected light microscopy, followed by solvent extraction of control samples to estimate the proportion of solvent soluble bitumen. Different phases of bitumen formation are differentiated by reflectance measurement as described for vitrinite reflectance measurement. Soluble extracts are fractionated to give alkane, aromatics, asphaltene and resene components. Separated bitumens may be subjected to elemental analysis.

Kerogen Typing Scheme for Transmitted White and Incident Blue/U.V. Light

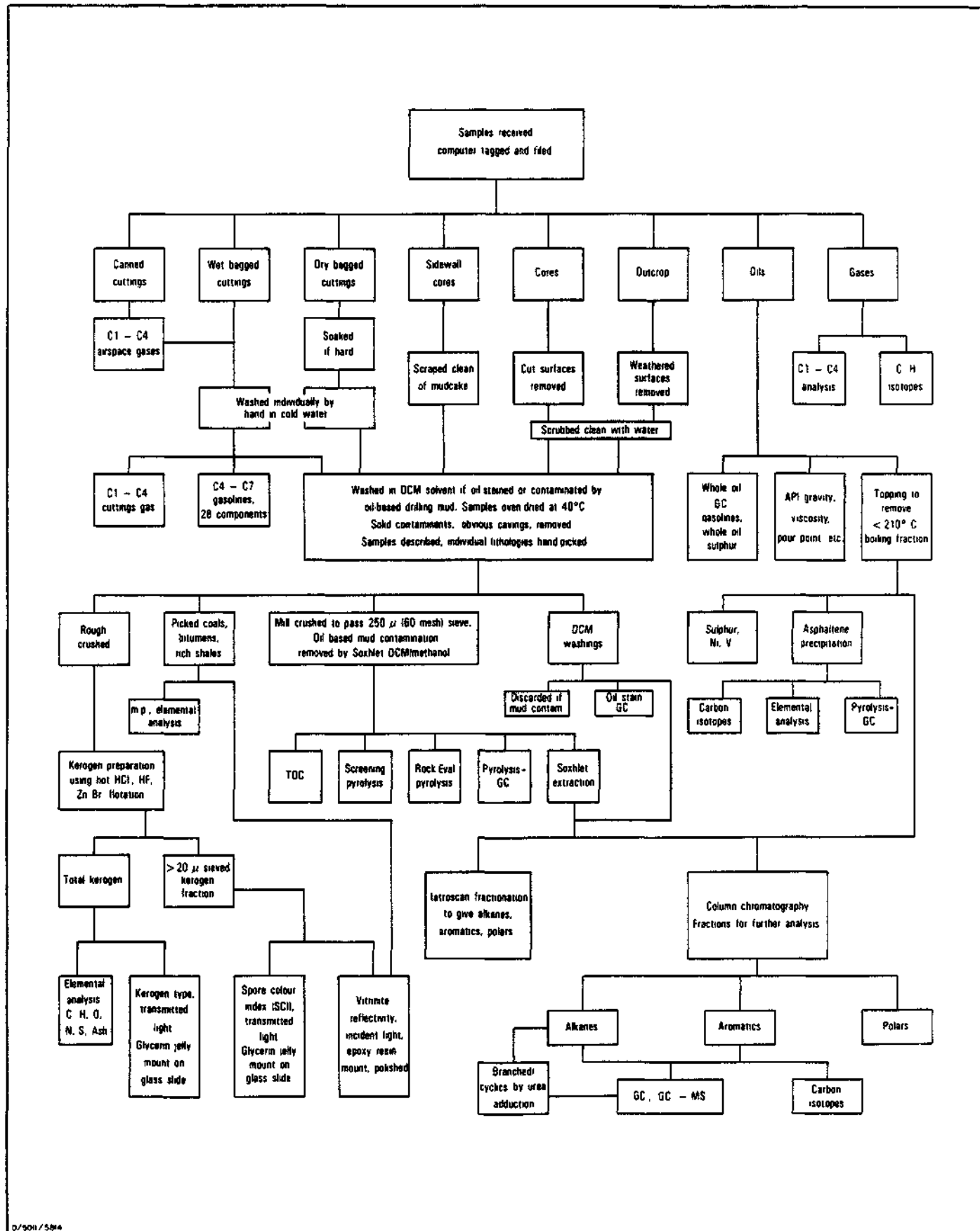
General Properties	RRI Report Data Tables	Type *
Sapropelic (Oil-prone gas-prone at high maturity)	Algal Sapropel	Type I
	Waxy Sapropel	Type II
Humic (Gas-prone)	Vitrinite	Type IIIA
	Inertinite	Type IIIB

Amorphous		Structured	
Non-Fluorescent	Fluorescent	Non-fluorescent	Fluorescent
Type I/II at high maturity (SCI >7.5)	Type I Sapropel Type II (degraded spores) Soft bitumens	Vitrinite (Type IIIA) brown/black, woody tissue	Cuticle Spores Pollen Dinocysts (Type II)
Type IIIA/B			
Oil residues (bitumens) Mineral (undigested) Grease contamination Mud additives		Inertinite (Type IIIB) very dark brown/black, woody tissue	Resinite Algae (Tasmanites, Botryococcus etc.) (Type I)
		Solid bitumen - brown/ black (oil residue) often with crystal imprints	
		Microforaminifera, chitinozoa etc. (Not usually important)	
		Spores, cuticle etc. at high maturity levels	
		Mud Additives - walnut etc.	

* Types I, II, III approximately sensu Tissot et al but Type III subdivided into IIIA (vitrinite) and IIIB (inertinite)

APPENDIX TABLE 1

FLOW CHART FOR GEOCHEMICAL ANALYSIS



APPENDIX FIGURE 1