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A Study of the Source Materials, Depositional Environments,
Mechanisms of Generation and Migration of Oils
in the Anadarko, Oklahoma

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The following report summarizes the work performed and results obtained during the third year of a three year funded proposal for DOE/BES. The major thrust of this work over the three year period has been the continued examination and characterization of oils and source rocks primarily collected from the Anadarko Basin. In the earlier parts of this study we concentrated mainly on the characterisation of oils and source rocks from the Pauls Valley area in the Anadarko Basin. It was concluded from that study that the majority of oils in that part of the Basin were sourced predominantly from the Woodford Shale with a smaller number of the oils being sourced and reservoired in the Viola Formation. In addition to that aspect of the work considerable time has been directed at understanding the effects of biodegradation by examining various oil seeps and tar sand samples in the Sulfur region of the Basin. The effects of weathering on the samples of the Woodford Shale has also been extensively studied and the results of both the biodegradation and weathering studies have already been published or are in press (see attached publication list).

For the past year our efforts have been concentrated on the examination of other potential source formations in the Anadarko Basin. Initially 200 samples were collected from the Viola, Sylvan, Springer and Morrow formations and screened by Rock Eval pyrolysis and TOC determination. The Viola and Sylvan are Ordovician and the Morrow and Springer are Pennsylvanian in age and this provides us with the opportunity to study two formations that are older than Woodford and two that are younger. Attempts were also made to to obtain these samples from over as wide an area as possible throughout the Basin (Fig. 1).

From the 200 samples initially screened by Rock-Eval pyrolysis, 80 were subsequently selected for more detailed geochemical analyses. The more detailed characterization has

included extraction, fractionation, analysis of the fractions by GC and GCMS and isotopic determination of the individual fractions. The insoluble residues are being characterized petrographically and by various pyrolysis techniques. Petrographic characterization is being performed with the assistance of Brian Cardott from the Oklahoma Geological Survey. The study forms the main part of the thesis project for one of my Ph.D. students and the initial stages of data collection are nearing completion. It is anticipated that further processing of data plus additional data acquisition will take at least another year. Some of the data that has already been obtained on these samples are summarized in Tables 1-5. Examples of some of the GCMS data already acquired are shown in Figs. 2-6.

In March of this year a new post-doctoral fellow joined us from the University of Aberdeen, Dr. Mahaboob Alam. He will be responsible for the day to day supervision of the program and I will assist him in this matter as necessary. Dr. Alam will work closely with the Ph.D. student on the project concerned with the source rocks as described above. In addition he has started to collect a number of oils covering a much wider region of the basin than we had previously examined. In particular we are trying to extend our coverage to the western and northern parts of the basin. In addition to the oils we have already in our collection we have just obtained an additional 40 oils from the USGS and Dr. Alam has already started to fractionate and analyses these oils. Obviously one of the aims of this part of the study is to extend the range of oil/source rock correlations into other parts of the basin, and to try and determine what contribution, if any, these other source formations are really making to the oils in the basin. One of the longer term goals of this study has always been to ultimately incorporate the geochemical data into a model for the generation of oil in this basin. Although

we are still someway from that goal, obviously the analyses of these additional samples will continue to bring us closer to the achievement of this goal.

In addition to the major thrust of this project as described above, we have continued with associated research in a number of related areas. Perhaps the most interesting of these has grown out of a project initially funded by NSF to study high molecular weight biomarkers ($> C_{40}$). We have collected and examined a number of waxes present in many of the pipelines and drill pipes of wells in the Anadarko Basin. These waxes were examined by GC and GCMS and found to contain hydrocarbons in carbon number up to at least C_{70-80} and probably higher. Interestingly enough the more specific biomarker compositions for the wax and their corresponding oils were identical. It is suggested that what is happening is that the wax is dissolved in the oil whilst in the reservoir. However as it is produced and the pressure and temperature are reduced, the waxes precipitate and do not actually reach the collection tanks. This observation of course is extremely important for a wide variety of reasons. Firstly what this is telling us is that the oil at the well head is not necessarily the same as the oil in the reservoir which could be important for enhanced oil recovery studies. To study this further we are currently negotiating with Texaco to obtain "fresh" reservoir cores from which we can actually extract the in-situ oil. A direct comparison can then be made between produced oil and oil in-place in a reservoir. We have also undertaken a number of in-situ maturation studies to investigate possible formation methods for these high molecular weight compounds and anticipate that this work will continue next year. Although initially the basic part of this search for higher molecular weight biomarkers was supported by NSF it is clear from the initial results that we are in a good position to use some of these results for our more applied research in the

Anadarko Basin.

In a more basic part of the program we have also spent some time investigating alternative extraction methods for bitumens from source rocks or other organic rich samples. In conjunction with a company called ISCO we have investigated the use of Super Critical Fluid Extraction (SFE) procedures for this purpose. The aim of the study was to subject source rock samples from the Anadarko Basin to extraction using both conventional Soxhlet extractors and SFE with CO₂ and various additives. Comparisons are being made to examine any variability that may have resulted in the biomarker distributions from these different processes. It is not possible to make a direct quantitative comparison for the simple reason the SFE with CO₂ alone does not extract the more polar components. Instead it extracts a relatively "clean" mixture of saturates and aromatics that can be analysed directly by GC and GC-MS. We have found that increasing the polarity of the CO₂ by the addition of methanol permits the extraction of the more polar components. Although work on this project is continuing, our results are extremely encouraging. It is felt that SFE provides a rapid and cheap alternative method for extracting source rocks. No solvents are involved and extractions are complete in approximately 10 minutes. The products are relatively clean, contain no polar or asphaltenes and can be analysed directly. To date the products obtained by SFE in terms of hydrocarbons are virtually identical to those obtained by soxhlet extraction. This development work will continue and it is hoped that we may soon be able to have access to a chromatograph which will enable us to evaluate the use of supercritical fluid chromatographs (SFC) for analytical purposes, particularly of high molecular weight components.

Finally we have continued with our efforts to develop and improve methods for the

analysis of biomarkers using MSMS and associated ancillary techniques. We have, during the course of the past two years, published several papers on these techniques and will not discuss then again in any more detail at this point. However it is anticipated that we will continue the aspect of this work particularly with regards to developing MSMS methods for analysing high molecular weight biomarkers analysed using the direct insertion probe. In addition we have also continued with our characterization of kerogens, asphaltenes and NSO-fractions by various pyrolysis approaches. Once again much of this work whilst extremely useful has become fairly routine and does not warrant a lengthy description here. We routinely analyse all of our insoluble residues by py-GC and determine hydrocarbons, organosulphur and organonitrogen compounds. Selected samples are then examined by py-GCMS using the PYRAN system purchased two years ago with the assistance of the DOE University Instrumentation Program.

Summary

This report is for the final year of a three-year funded project. A new proposal has been submitted and it is hoped that funding will continue for another three years. It is felt that good progress is being made with our work on studying the oils and source rocks in the Anadarko Basin. Furthermore a number of associated projects have evolved during this period which have also produced many useful results and various analytical methods have been developed. In Appedix I lists of students totally or partially supported by this work plus various publications are given. It is hoped that these will testify to our productivity arising from the DOE support over the past few years.

Appendix I

Student theses resulting from total or partial DOE support

Student's Name (Last name, first)	Degree	Date (Mo/Yr)	Thesis/Dissertation Title
Jones, Peter J.	M.S.	6/86	Oil and source rocks from Paul Valley area, Anadarko basin.
Oung, Jung Nan	M.S.	6/87	The geochemical significance of tricyclic terpanes.
Lin, Li-Hua	M.S.	6/87	Effects of biodegradation on tar sand bitumen of South Woodford area, Carter County, Oklahoma.
Bakel, Allen	M.S.	6/87	Organosulfur and organic nitrogen compounds in oils, asphaltenes, kerogens and oils.
Michael, G.E.	M.S.	12/87	Effect of biodegradation upon porphyrin biomarkers in Upper Mississippian tar sands and related oils, southern Oklahoma.
Galvez-Sinibaldi, A.	M.S.	5/88	Characterisation of possible kerogen precursors by pyrolysis-gas chromatography.
Oung, J-N.	Ph.D.	5/89	MS/MS in biomarker determination.
Bakel, A.	Ph.D.	12/90	The Geochemistry of Nitrogen in Crude Oils.

Ruble, T.

M.S.

12/90

Organic Geochemical Investigation of Native Bitumens from the Uinta Basin, Utah, U.S.A.

Publications resulting from total or partial DOE support.

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Table 1. Selected samples used in the study after screening
and their lithology

S.No.	Well.No.	Location	Depth	Lithology Discription	% Carb
VIO-02	(01)	1N 2W 7	6687-689	Black, Coarse crystal Carbonate	67.8
VIO-06	(02)	1N 2W 7	7208-209	Black, Micro cry, Lami, Fossil Carbonate	84.6
VIO-12	(04)	1N 2W18	6561-564	Dark, Micro cry Carbonate	51.6
VIO-14	(05)	1N 2W18	8191-194	Black, Fine cry Carbonate	74.6
VIO-16	(07)	1N 3W12	9206-209	Black, Fine cry Carbonate	58.6
VIO-18	(09)	3N 2W22	5942-945	Black, Fine cry, Fossil Carbonate	47.0
VIO-22	(11)	5N 5W36	12006-009	Black, Coarse cry Carbonate	84.3
VIO-25	"	"	12251-254	Black, Fine cry Carbonate	92.4
VIO-28	"	"	12627-630	Dark, Calcareous Siltstone	3.6
VIO-38	(12)	5N12W 2	2666-280	Grey, Fine cry, Lami Carbonate	80.8
VIO-52	(15)	7N13W30	5866-869	Dark, Coarse cry Carbonate	73.6
VIO-56	(18)	9N 2W16	7461-464	Dark, Fine cry, Lami Carbonate	87.7
VIO-59	(19)	9N 3W31	9723-726	Black, Fine cry, Calcareous Shale	37.4
VIO-60	"	"	10122-149	Greenish dark, Fine cry, Shale	5.6
VIO-65	(22)	14N 2W15	6106-116	Black, Loose Shale//Dark siltstone	16.9
VIO-69	(27)	2S 6W32	2962-965	Dark brown, Micro cry Carbonte	65.3
SYL-01	(01)	1N 2W17	7295-296	Dark brown/black, Fine cry Carbonate	63.0
SYL-03	(02)	5N 3W27	7773-774	Black, Micro cry Carbonate with Grey porphritic crystals	86.9
SYL-06	(04)	6N15W22	845-849	Black, Micro cry, Waxy Shale	19.5
SPR-03	(02)	1N 4W 7	7200-227	Black Shale//Grey Siltstone	7.0
SPR-04	(03)	1N 5W28	11290-293	Black Siltstone	8.2
SPR-09	(06)	3N 4W12	9481-491	Black Shale//Black Siltstone	10.9
SPR-11	(08)	4N 8W 5	15019-020	Black Shale//Dark Siltstone	12.2
SPR-13	(09)	5N 6W23	11948-949	Black Shale//Dark Siltstone	8.7
SPR-15	"	"	12010-011	Black Shale	4.4
SPR-20	(11)	5N10W17	18076-079	Grey Siltstone (Some black materials)	4.1
SPR-28	(14)	7N 3W31	9560-563	Black, Silky Shale	6.3
SPR-31	(15)	7N16W 2	4220-240	Yellowish brown, Loose Mustone	7.3
SPR-37	(16)	7N16W 2	5799-800	Black Shale//Brown calcareous Siltstone	17.8
SPR-38	(17)	8N 8W31	10770-785	Black Shale	8.1
SPR-42	(20)	9N 9W22	13823-837	Black Shale	7.1
SPR-47	(22)	11N12W10	14000-016	Black Shale	12.2
SPR-49	(23)	12N16W10	15882-893	Black Shale	5.7
SPR-51	(25)	15N17W32	12899-900	Black Shale	28.3
SPR-53	(26)	21N11W 9	6920-921	Dark brown, Fine cry Carbonate	44.2
SPR-58	(29)	1S 4W12	4748-767	Black Shale//Dark Siltstone	7.1
SPR-60	(30)	1s 4w32	6426-438	Black calcareous Siltstone	28.1
SPR-62	(32)	2S 3W20	5836-840	Black Shale//Dark Siltstone	6.5
SPR-64	(33)	3S 3W16	10337-340	Black Shale w/ Calcareous grains	10.9
SPR-66	(07)	4N 6W 4	11717-721	Grey to dark Siltstone	5.3
SPR-72	(13)	6N 9W14	16537-540	Grey Siltstone//Black Shale (Very dense, Hard)	3.8
MOR-02	(02)	5N 8W28	13741-744	Black Shale	7.8
MOR-11	(04)	8N 5W36	14628-630	Black, Waxy Shale	9.8

MOR-16	(05)	8N17W20	16304-305	Black Shale	10.4
MOR-31	(14)	11N20W12	14990-090	Black, Silty Carbonate	16.9
MOR-33	(15)	12N21W 3	18906-909	Black Shale	10.1
MOR-37	(17)	13N 8W30	9931-934	Black, Silty Carbonate	21.5
MOR-39	(19)	14N10W26	10152-171	Black Shale//Grey Siltstone	9.9
MOR-41	(20)	15N11W18	10263-269	Black Shale	28.2
MOR-43	(21)	15N12W31	10808-816	Black Shale	7.4
MOR-44	(22)	15N17W32	12728-748	Dark grey Shale//Thin, Black Shale	7.0
MOR-57	(29)	18N14W25	9071-077	Black calcareous Shale	14.5
MOR-66	(36)	19N12W33	8253-263	Black calcareous Shale	16.9
MOR-67	(37)	19N14W22	8385-388	Dark Siltstone w/ Bitumen	5.7
MOR-68	(38)	19N15W 4	8335-338	Black shaly Carbonate	50.9
MOR-71	(40)	20N17W32	9180-185	Black, Coarse cry Carbonate	53.2
MOR-74	(42)	20N17W33	10392-395	Greenish dark Shale	12.4
MOR-75	(43)	21N17W19	7896-899	Dark, Loose Shale	5.6
MOR-83	(49)	21N21W14	9170-173	Dark, Grey Shale	7.0
MOR-91	(57)	24N20W21	7463-466	Black Shale	5.1
MOR-97	(60)	24N26W36	8218-222	Dark grey calcareous Siltstone	17.1

Table 2. Carbon isotope data for selected samples

Sample	Saturate	Aromatics
VIO-02	-30.68	-29.75
VIO-04	-30.78	-30.07
VIO-06	-30.60	-29.85
VIO-12	-31.15	-30.09
VIO-14	-32.81	-32.38
VIO-16	-31.11	-29.93
VIO-18	-30.98	-30.20
VIO-22	-31.05	-29.73
VIO-38	-30.72	-29.61
VIO-52	-30.69	-29.54
VIO-56	-30.89	-29.68
VIO-59	-30.82	-29.14
SYL-01	-30.91	-29.16
SYL-03	-30.49	-28.84
SPR-03	-29.20	-27.48
SPR-04	-28.65	-24.84
SPR-09	-28.60	-26.42
SPR-13	-28.49	-25.68
SPR-15	-28.15	-25.27
SPR-28	-31.60	-31.04
SPR-38	-30.43	-26.09
SPR-42	-30.21	-26.25
SPR-47	-29.58	-26.42
SPR-49	-29.62	-24.52
SPR-60	-30.95	-30.03
SPR-62	-29.91	-26.60
SPR-64	-29.32	-24.79
MOR-02	-26.34	-25.30
MOR-11	-28.77	-24.50
MOR-16	-31.47	-25.58
MOR-33	-30.08	-28.16
MOR-39	-30.09	-24.84
MOR-41	-29.43	-26.40
MOR-43	-29.09	-25.09
MOR-57	-28.07	-24.69
MOR-64	-30.43	-29.22
MOR-66	-30.70	-29.69
MOR-68	-30.09	-29.36
MOR-74	-26.30	-24.60
MOR-75	-29.20	-24.73
MOR-86	-26.04	-25.11
MOR-91	-28.17	-25.38

Table 3. Extraction data of the selected samples

Sample	W (g)	Dasg (mg)	Asp (mg)	EOM (ppm)	Sat (mg)	%	Aro (mg)	%	NSO (mg)	%	THC (ppm)
VIO-02	109.9	74.6	9.73	767	18.73	52.6	2.58	7.2	14.31	40.2	406
VIO-04	92.5	605.9	45.34	7041	39.58	62.2	7.00	11.0	17.05	26.8	4795
VIO-06	104.5	216.8	29.94	2362	43.20	56.5	10.98	14.4	22.28	29.1	1470
VIO-12	96.6	513.7	72.01	6063	29.17	41.4	13.96	19.8	27.29	38.8	3257
VIO-14	101.0	669.0	108.58	7698	27.77	33.5	24.35	29.4	30.84	37.2	4161
VIO-16	109.6	76.2	25.38	927	21.65	49.2	4.75	10.8	17.64	40.1	417
VIO-18	112.9	47.6	15.05	555	9.40	25.9	6.00	16.5	20.93	57.6	179
VIO-22	102.2	66.3	8.54	732	36.51	61.1	6.77	11.3	16.49	27.6	470
VIO-38	100.1	209.9	47.94	2576	38.33	53.5	9.33	13.0	24.01	33.5	1394
VIO-52	89.1	35.1	1.52	411	17.95	59.3	2.79	9.2	9.54	31.5	270
VIO-56	119.2	400.2	83.89	4061	35.72	53.3	14.02	20.9	17.24	25.7	2493
VIO-59	89.5	46.5	4.48	570	22.25	56.0	3.37	8.5	14.09	35.5	335
SYL-01	117.3	206.1	26.18	1981	40.17	53.5	8.10	10.8	26.87	35.8	1129
SYL-03	114.7	144.4	45.91	1659	25.54	50.3	6.00	11.8	19.24	37.9	782
SPR-03	124.4	48.3	26.69	603	23.56	52.3	3.73	8.3	17.74	39.4	235
SPR-04	111.7	31.9	44.95	688	3.14	12.0	6.67	25.5	16.35	62.5	107
SPR-09	111.7	40.2	2.66	384	12.68	59.3	2.83	13.2	5.88	27.5	261
SPR-13	99.5	61.4	69.76	1318	3.46	9.1	6.33	16.7	28.18	74.2	159
SPR-15	130.4	58.7	81.56	1076	4.68	11.0	8.24	19.4	29.46	69.5	137
SPR-28	65.7	508.3	104.03	9320	24.92	38.2	13.78	21.1	26.56	40.7	4588
SPR-38	83.1	20.9	9.12	361	7.10	51.2	1.49	10.8	5.27	38.0	156
SPR-42	99.8	88.7	7.30	962	16.71	48.7	4.95	14.4	12.62	36.8	562
SPR-47	95.9	12.5	5.13	184	3.39	38.3	1.63	18.4	3.82	43.2	74
SPR-49	97.0	5.4	4.24	99	1.10	39.9	0.48	17.4	1.18	42.8	32
SPR-60	107.9	100.7	43.00	1332	11.27	27.6	8.86	21.7	20.64	50.6	461
SPR-62	115.8	57.5	55.50	976	12.80	27.4	7.62	16.3	26.22	56.2	217
SPR-64	98.1	137.3	70.60	2119	4.60	8.5	5.66	10.5	43.58	80.9	267
MOR-02	91.8	26.3	8.70	381	6.68	34.6	3.09	16.0	9.55	49.4	145
MOR-11	90.5	12.4	6.53	209	2.46	29.4	1.92	22.9	4.00	47.7	72
MOR-16	91.3	47.0	5.81	578	28.40	78.6	2.21	6.1	5.50	15.2	436
MOR-33	102.8	17.4	8.16	249	9.23	63.5	2.53	17.4	2.78	19.1	137
MOR-39	100.4	14.6	13.84	283	6.52	46.1	2.28	16.1	5.34	37.8	91
MOR-41	81.9	16.6	9.74	322	4.20	37.2	1.85	16.4	5.23	46.4	109
MOR-43	106.7	22.1	10.36	304	3.12	34.0	2.31	25.2	3.75	40.8	123
MOR-57	70.4	33.2	27.27	859	6.85	25.3	5.87	21.7	14.36	53.0	222
MOR-64	92.4	120.6	23.11	1555	26.18	50.5	5.42	10.4	20.27	39.1	795
MOR-66	90.1	149.5	29.74	1989	26.65	51.5	7.25	14.0	17.88	34.5	1086
MOR-68	90.8	35.3	8.19	479	16.83	56.1	4.03	13.4	9.12	30.4	271
MOR-74	103.4	19.7	9.21	280	3.82	26.1	3.68	25.1	7.14	48.8	98
MOR-75	100.2	20.2	19.23	394	2.75	15.8	6.06	34.9	8.57	49.3	102
MOR-86	90.4	18.6	8.46	299	10.44	46.6	2.05	9.2	9.89	44.2	115
MOR-91	111.0	38.3	9.95	435	8.88	32.3	5.43	19.8	13.15	47.9	180

Table 4. GC data from extracts of the selected samples

Sample	25- 33	23- 31	24- 32	CPI	Pr	Ph	nC1	nC	nC2	iC18	Pr/ Ph	Pr/ nC17	Ph/ nC18	nC17 nC25	iC18 nC17	Peak
VIO-02	299	438	461	0.80	91.6	87.8	179	168	111	43.2	1.04	0.51	0.52	1.61	0.24	nC24
VIO-04	319	468	392	1.00	23.8	40.9	63	100	128	10.1	0.58	0.38	0.41	0.49	0.16	nC21
VIO-06	422	685	566	0.98	155	160	455	442	202	71.2	0.97	0.34	0.36	2.25	0.16	nC19
VIO-12	353	518	451	0.97	193	143	393	319	140	98.9	1.35	0.49	0.45	2.81	0.25	nC17
VIO-14	641	810	769	0.94	184	190	555	369	195	89.4	0.97	0.33	0.51	2.85	0.16	nC17
VIO-16	309	405	355	1.01	76.9	87	522	412	101	38.0	0.88	0.15	0.21	5.17	0.07	nC19
VIO-18	377	498	464	0.94	132	83.9	657	387	125	69.3	1.57	0.20	0.22	5.26	0.11	nC17
VIO-22	695	1005	832	1.02	65.7	64	203	202	277	30.2	1.03	0.32	0.32	0.73	0.15	nC21
VIO-38	407	598	508	0.99	101	89.1	411	380	150	46.4	1.13	0.25	0.23	2.74	0.11	nC19
VIO-52	601	727	697	0.95	146	87.3	383	330	168	74.7	1.67	0.38	0.26	2.28	0.20	nC17
VIO-56	392	534	470	0.99	136	104	246	248	137	70.0	1.31	0.55	0.42	1.80	0.28	nC18
VIO-59	510	912	657	1.08	142	95.8	1083	545	174	94.8	1.48	0.13	0.18	6.22	0.09	nC17
SYL-01	144	236	181	1.05	335	202	658	496	58.7	192.0	1.66	0.51	0.41	11.2	0.29	nC17
SYL-03	564	853	693	1.02	212	220	146	165	259	80.3	0.96	1.45	1.33	0.56	0.55	nC23
SPR-03	98	129	108	1.05	43.2	39.1	201	181	31.5	18.1	1.10	0.21	0.22	6.38	0.09	nC17
SPR-04	653	1186	927	0.99	65.6	47.5	166	165	373	27.7	1.38	0.40	0.29	0.45	0.17	nC23
SPR-13	87	134	105	1.05	121	67.5	365	286	30.3	75.4	1.79	0.33	0.24	12.0	0.21	nC17
SPR-15	493	752	595	1.05	249	117	616	511	193	140.0	2.13	0.40	0.23	3.19	0.23	nC17
SPR-28	129	186	152	1.04	144	83.2	243	169	48.1	111.0	1.73	0.59	0.49	5.05	0.46	nC15
SPR-38	121	198	154	1.04	474	348	914	721	47.4	284.0	1.36	0.52	0.48	19.3	0.31	nC17
SPR-47	229	429	323	1.02	147	113	384	318	117	87.0	1.30	0.38	0.36	3.28	0.23	nC17
SPR-49	536	930	736	1.00	144	100	341	292	300	73.1	1.44	0.42	0.34	1.14	0.21	nC22
SPR-60	1153	2138	1631	1.01	345	293	439	326	698	165.0	1.18	0.79	0.90	0.63	0.38	nC23
SPR-62	318	445	331	1.15	500	213	787	523	112	266.0	2.35	0.64	0.41	7.03	0.34	nC16
SPR-64	855	1455	1051	1.10	374	249	883	872	415	150.0	1.50	0.42	0.29	2.13	0.17	nC18
MOR-02	368	549	462	0.99	305	197	581	528	169	159.0	1.55	0.52	0.37	3.44	0.27	nC17
MOR-11	190	273	270	0.86	197	132	514	311	87.3	134.0	1.49	0.38	0.42	5.89	0.26	nC16
MOR-16	875	1571	1197	1.02	156	117	200	221	505	49.4	1.33	0.78	0.53	0.40	0.25	nC23
MOR-33	1615	2009	1785	1.02	311	177	795	500	452	176.0	1.76	0.39	0.35	1.76	0.22	nC17
MOR-39	117	149	132	1.01	144	67.1	314	169	38.6	105.0	2.15	0.46	0.40	8.13	0.33	nC16
MOR-41	152	229	180	1.06	170	100	422	271	60.5	113.0	1.70	0.40	0.37	6.98	0.27	nC16
MOR-43	148	326	257	0.92	100	69.9	224	160	88.9	60.5	1.43	0.45	0.44	2.52	0.27	nC17
MOR-57	342	508	446	0.95	191	95.7	454	380	186	94.8	2.00	0.42	0.25	2.44	0.21	nC17
MOR-64	441	791	606	1.02	215	169	414	374	254	121.0	1.27	0.52	0.45	1.63	0.29	nC18
MOR-66	382	531	437	1.04	215	138	299	251	174	124.0	1.56	0.72	0.55	1.72	0.41	nC17
MOR-68	412	892	635	1.03	145	87.4	237	212	255	76.3	1.66	0.61	0.41	0.93	0.32	nC22
MOR-74	240	1124	607	1.12	38.7	38.7	116	111	182	20.2	1.00	0.33	0.35	0.64	0.17	nC23
MOR-75	296	388	347	0.99	208	96.5	420	245	129	124.0	2.16	0.50	0.39	3.26	0.30	nC16
MOR-86	741	942	848	0.99	83.3	48.6	213	189	241	54.1	1.71	0.39	0.26	0.88	0.25	nC27
MOR-91	211	413	294	1.06	281	223	729	539	100	160.0	1.26	0.39	0.41	7.29	0.22	nC17

Table 5. Aromatic data of the selected samples

Sample	Phena	M-3	M-2	M-9	M-1	MPI
VIO-02	48.3	59.2	53.6	106	70.7	0.75
VIO-04	16.5	22.9	14.9	26.8	18.2	0.92
VIO-06	179	114	116	190	151	0.66
VIO-12	34	26.4	20.8	32.1	21.8	0.81
VIO-14	31.5	20.3	14.5	17.3	17.5	0.79
VIO-16	51.8	64.1	59.9	122	211	0.48
VIO-18	96.9	37.4	45.4	64.7	53.9	0.58
VIO-22	40.1	41.6	39.7	63.6	45.9	0.82
VIO-38	208	164	118	201	179	0.72
VIO-52	26.1	22.6	21.3	25.2	20.7	0.91
VIO-56	43.1	43.5	32.1	48.2	40.2	0.86
VIO-59	211	144	85.1	154	144	0.68
SYL-01	156	87	86	76	65	0.87
SYL-03	73.9	53	49	114	42	0.67
SPR-03	326	166	201	124	109	0.98
SPR-04	356	126	142	154	95	0.66
SPR-09	317	231	247	152	117	1.22
SPR-13	471	206	248	326	226	0.67
SPR-15	262	100	113	134	85	0.66
SPR-28	57.3	36.4	36.4	70.1	55.3	0.60
SPR-38	153	93.5	116	39	33	1.40
SPR-42	457	239	302	107	96	1.23
SPR-47	229	134	168	61.3	47.1	1.34
SPR-49	121	53.9	74.8	21.1	15.6	1.22
SPR-60	200	113	114	146	118	0.73
SPR-62	723	221	244	278	209	0.58
SPR-64	719	210	236	243	173	0.59
MOR-02	222	160	183	160	136	0.99
MOR-11	196	117	140	84.4	63.8	1.12
MOR-16	127	90	111	26.5	22	1.72
MRO-33	101	35.3	32.4	26.8	10	0.74
MOR-39	714	479	516	180	170	1.40
MOR-41	245	141	157	117	96.7	0.97
MOR-43	444	244	297	149	121	1.14
MOR-57	762	304	414	347	320	0.75
MOR-64	176	102	108	115	103	0.80
MOR-66	161	89.7	97.5	158	138	0.61
MOR-68	88.9	49.9	52.1	90.9	77.7	0.59
MOR-74	470	354	460	267	245	1.24
MOR-75	381	107	123	150	114	0.53
MOR-86	305	188	230	185	175	0.94
MOR-91	820	328	411	413	325	0.71

FIGURE CAPTIONS

Fig. 1. Map of the Anadarko Basin showing sample locations for this study.

LEGEND

- ▲ Viola & Sylvan rock samples
Extracted, detailed analyses
- △ Viola & Sylvan rock samples
Unextracted, pyrolysis only
- Morrow & Springer rock samples
Extracted, detailed analyses
- Morrow & Springer rock samples
Unextracted, pyrolysis only
- ★ Crude oil samples
Detailed analyses

The Sample location map of
the Anadarko Basin Project

Fig. 2. M/z 191 and 205 chromatograms for the Viola rock extracts show a number of interesting features which will be investigated in more detail in the next few months. For instance in this chromatogram in addition to all of the regular hopanes, this extract also contains 25,28-bisnorhopane; the series of $18\alpha(H)$ -neohopanes; and series of both 2- and 3- methyl hopanes. The complexity and diversity of the hopane series in these extracts should greatly facilitate any correlation studies with oils thought to be derived from the Viola.

LIRO: NHD4784 ver 1 on UIC 2 2 12-MAR-91 Elapse: 00:10:23 1
Samp: VIO-14R ROCK EXTRACT SAT Start : 14:20:20 3026
Comm: MS=MIDWHD GC=FXH 14 IONS
Mode: EI +Q3MS LMR UP LR
Oper: NHD
Peak: 1000.00 mmu Label wndw: 1000 > 3550 Masses: 110 > 259
Area: 0, 4.00 Baseline : 0, 3 Label : 0, 40.00

Fig. 3. The steranes are also extremely interesting in that they contain relatively high concentrations of $\beta\beta$ -steranes whilst the $\alpha\alpha$ 20S and 20R series still appears relatively immature, implying that the high $\beta\beta$ -sterane concentration may be source related not maturity related. Note also the high concentration of C_{29} steranes typical in these Ordovician samples despite the absence of land plant material.

CHRO: WHD4784 ver 1 on UIC 2 2

12-MAR-91 Elapse: 00:10:23 1

Samp: VIO-14R ROCK EXTRACT SAT

Start : 14:20:20 3826

Comm: MS=MIDNHD GC=FXH 14 IONS

Mode: EI +Q3MS LMR UP LR

Oper: WHD

Inlet : GC

Peak: 1000.00 mmu Label undw: 1200 > 3000

Masses: 110 > 259

Area: 0, 4.00

Baseline : 0, 3

Label : 0, 40.00

Fig. 4. M/z 191 and 205 for an oil collected from the Viola Formation. The terpane distributions were virtually identical with the exception of the relatively low concentration of the bisnorhopane. Both series of methyl hopanes again present in this sample as in the source rock extract.

CHRU: HHD4432 ver 2 on UIC 2 2

1-OCT-90 Elapse: 00:05:16 1

Samp: P-20 SAT

Start : 00:01:55 3993

Coma: MID 13 IONS GC=FXH ICL=MIDAG

Mode: EI +Q3MS LMR UP LR

Oper: HHD

Inlet : GC

Peak: 1000.00 mmu

Label wndw: 1100 > 3450

Masses: 110 > 259

Area: 0, 4.00

Baseline : 0, 3

Label : 0, 40.00

Fig. 5. M/z 217 chromatogram for the same oil as used in Fig. 4. Distribution of the steranes here is virtually identical to that observed in the Viola rock extract.

CHRO: WHD4431 ver 1 on UIC 2 2 30-SEP-90 Elapse: 00:05:16 1
Samp: P-10 SAT Start : 20:14:33 3994
Comm: MID 13 IONS GC=FXH ICL=MIDAG
Mode: EI +Q3MS LMR UP LR
Oper: WHD Inlet : GC
Peak: 1000.00 mmu Label wndw: 1300 > 3000 Masses: 110 > 259
Area: 0, 4.00 Baseline : 0, 3 Label : 0, 40.00

Fig. 6. The m/z 191, 205 and 217 chromatograms for the oil P10 also recovered from the Viola Formation shows a number of subtle differences suggesting that although P10 is sourced from the Viola, it may have had a somewhat different origin, maybe a different facies within the Viola. In particular note the much lower concentrations of the methylhopanes in P10, higher tricyclic concentrations in P10, lower C_{29}/C_{30} hopane ratios in P10 and lower 25,28 bisnorhopane concentration in P10. The sterane distributions show some minor differences which may be maturity related, note the higher concentration of pregnanes in P10.

CHRO: WHD4431 ver 1 on UIC 2 2

30-SEP-90 Elapse: 00:05:16 1

Samp: P-10 SAT

Start : 20:14:33 3994

Comm: MID 13 IONS GC=FXH ICL=MIDAG

Mode: EI +Q3MS LMR UP LR

Oper: WHD

Inlet : GC

Peak: 1000.00 mmu Label wndw: 1100 > 3450

Masses: 110 > 259

Area: 0, 4.00

Baseline : 0, 3

Label : 0, 40.00

RO: WHD4432 ver 2 on UIC 2 2 1-OCT-90 Elapse: 00:05:16 1
mp: P-20 SAT Start : 00:01:55 3993
mm: MID 13 IONS GC=FXH ICL=MIDAG
de: EI +Q3MS LMR UP LR
er: WHD Inlet : GC
ak: 1000.00 mmu Label wndw: 1300 > 3000 Masses: 110 > 259
ea: 0, 4.00 Baseline : 0, 3 Label : 0, 40.00